Joint
Transportation
Research
Program

JTRP

FHWA/IN/JTRP-98/2

Final Report

PART I
LABORATORY PROCEDURES MANUAL

IMPLEMENTATION OF SUBGRADE RESILIENT MODULUS FOR PAVEMENT DESIGN AND EVALUATION

A. G. Altschaeffl
R. A. Duckworth
M. K. Clough

February 1998

Indiana
Department
of Transportation

Purdue
University

FINAL REPORT

"Implementation of Subgrade Resilient Modulus
for Pavement Design and Evaluation"

FHWA/INDOT/JTRP-98-2
Part I – "Laboratory Procedures Manual"

by

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Purdue University
School of Civil Engineering
Joint Transportation Research Project
Project No. C-36-52Q
File No. 6-20-16

Prepared in Cooperation with the
Indiana Department of Transportation and
the U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Federal Highway Administration and the Indiana Department of Transportation. This report does not constitute a standard, a specification, or a regulation.

Purdue University
West Lafayette, Indiana 47907
February 1998

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http://www.archive.org/details/implementationof00alts

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-98/2		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Implementation of Subgrade Resilient Modulus for Pavement Design and Evaluation, Part I and Part II	5. Report Date: February 1998 6. Performing Organization Code
7. Author(s) A. G. Altschaeffl, R.A. Duckworth, and M. K. Clough	8. Performing Organization Report No. FHWA/IN/JTRP-98/2
9. Performing Organization Name and Address Joint Transportation Research Program 1284 Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	10. Work Unit No. 11. Contract or Grant No. SPR-2134
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract

This Implementation Project had two purposes:

1) to update the INDOT Division of Materials and Tests' laboratory equipment and train personnel to properly conduct the testing for subgrade resilient modulus in accordance with new AASHTO testing protocol (AASHTO T-294-94);
2) to educate and train the geotechnical engineering section in the procedures for determining the design resilient modulus with minimum required testing, while using the database of the previous report on this subject, FHWA/IN/JHRP-92/23, "Subgrade Resilient Modulus for Pavement Design and Evaluation."

Part I of the Final Report, the detailed "Laboratory Procedures Manual," has been written for use by laboratory technicians having no formal engineering background. INDOT Materials and Tests Division personnel have been trained in performing the tests to the satisfaction of supervisory personnel.

Part II of the Final Report, "Design Subgrade Resilient Modulus," is the detailed summary of the procedures to be used in determining the design modulus for a project. In-service changes in water content and freeze-thaw effects are included. This report allows INDOT design engineering personnel to use laboratory test results and the previous database to determine properly the design resilient modulus for both new construction and in-service pavements.

17. Key Words	18. Distribution Statement
subgrade resilient modulus; pavement design.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	77	

Form DOT F 1700.7 (8-69)

Final Report

"Implementation of Subgrade Resilient Modulus
for Pavement Design and Evaluation"

To: Professor K. C. Sinha
Joint Transportation Research Project

From: A. G. Altschaeffl

February 1998

Project C-36-52Q

File 6-20-16

The Final Report on subject project is transmitted to you in 2 parts. Part I is a detailed "Laboratory Procedures Manual"; this has been written for use by laboratory technicians having no formal engineering background. INDOT Division of Materials and Tests personnel have been trained in following these procedures to the satisfaction of supervisory personnel.

Part II, "Design Subgrade Resilient Modulus", is the detailed summary of the procedures to be used in determining the design modulus for a project. This report allows INDOT design engineering personnel to use laboratory test results, and the data base from a previous project (FHWA/INDOT/JHRP-92-23) to determine properly the design resilient modulus for both new construction and in-service pavements.

This implementation project follows the previous SPR project whose report is referenced above. The testing protocol for resilient modulus has changed from the earlier project's AASHTO T-274-82 to the current AASHTO T-294-94. Because of this, and because INDOT wished to be able to test soils not explicitly in the previous project's data base, it was decided to create the current implementation project. Two components comprised this project: 1) update INDOT Division of Materials and Tests laboratory equipment, create necessary testing capabilities, and train technical personnel; 2) educate and train the geotechnical engineering section of the Materials and Tests Division, so to minimize testing to be required in determining the design resilient modulus for a project.

The contents of the two parts of this Final Report show that the objectives of the project have been fulfilled. Equipment updating was readily accomplished. Unfortunately, the original organization for software support unilaterally withdrew from the market. In-house operations managed to work around this major obstacle, albeit over a longer time frame. Laboratory personnel are now trained, ready for work. Design engineering personnel now can conform fully to the mandates of the AASHTO Guide for the Design of Pavement Structures with respect to the subgrade soils.

The contents of this report reflect totally the comments made by SAC reviewers. These comments improved this report and they are acknowledged and appreciated.

Respectfully submitted,

A. G. Altschaeffl
Research Engineer

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March 4, 1998

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Attention: Professor A. G. Altschaeffl

Re: "Implementation of Subgrade Resilient Modulus for Pavement Design and Evaluation" - Project C-36-52 Q

Prof. Altschaeffl:

Ross Duckworth has successfully completed the training phase of this project and is in the process of completing a draft of the procedure manual. Our Geotechnical Laboratory Supervisor and one Laboratory Technician have been trained and have demonstrated proficiency in conducting the procedures necessary to produce accurate results.

One variation in the original proposal for this work had to be accepted. The computer program will produce data only in non-metric form and that must be manually converted to metric units. This is not a crippling flaw, but it is a deviation from the original proposal. Through no fault of either the researchers or INDOT, we were unable to get the cooperation of either the equipment manufacturer (MTS Corporation) or the software designer Dr. G. Sousa in supporting the products they manufactured, since they had terminated their contractual relationship. The attempts at contacting Dr. Sousa resulted in two time extensions on this project. The result was that we were ignored and the decision was made that the project was important enough to warrant completion with this change.

Please contact us, if you require additional information. We look forward to reviewing the draft report.

R. K. Smutzer P.E.
Chief, Materials and Tests Division

rwr/RWR

cc: J. P. Bellinger
R. W. Rahn
N. Zia
File

INDoT Resilient Modulus of Subgrade Soil Laboratory Procedures Manual

20 February 1998

Comments for INDoT Directors, Supervisors, and Engineers

(Remove this from laboratory copies of manual)

The apparatus, training, and laboratory procedures manual provided to INDoT are, at the request of INDoT, intended for use by laboratory technicians with a non-technical general education.

This is therefore a user manual intended for operating technicians, rather than engineering staff. INDoT Laboratory technicians trained in Soils Resilient Modules are able to prepare samples, conduct the test, collect the test data, and provide a test result in the form of a data reduction and plot. The proper analysis and interpretation of the data, as well as engineering conclusions, must be made by a qualified geotechnical engineer with some experience in Resilient Modulus of Subgrade Soil.

Not all soil samples are suitable for determination of Resilient Modules by the AASHTO T-294 method. An incomplete test result may indicate that the soil specimen failed before completion of the T-294 sequence of tests. Such soils have a resilient modulus value so low that they are not suited to the T-294 method.

This test and the test apparatus are complex. Before attempting to run the Resilient Modules test, laboratory technicians must have thorough knowledge and experience with general soils classification tests, sample preparation, desktop computer operation and files manipulation, triaxial tests of soils, and the operation of the MTS machine. The training time for an otherwise trained technician to be able to learn the Resilient Modulus test is estimated at two weeks, full time training. The turnover and transition time for a new technician assigned to this test is estimated at three to six months.

Two technicians at Materials and Tests have been trained to the satisfaction of the laboratory supervisor. It is highly recommended that the training of a replacement technician begin immediately in the event that one of the existing trained technicians is lost from the INDoT staff.

Several trials with running dummy samples and trial samples will be required before a technician should be expected to run tests for research or engineering purposes.

Once trained and experienced with the test procedures, it is reasonable to expect that a laboratory technician will be able to run two resilient modulus tests per day.

Resilient Modulus of Subgrade Soils

AASHTO T294-94

Laboratory Procedures for Technicians

Indiana Department of Transportation,
Division of Materials and Tests

-and-

Purdue University School of Civil Engineering
Joint Highway Research Project SPR-2134

20 February 1998

I. Resilient Modulus of Soils

Soils Resilient Modulus, in this case a laboratory test specified by AASHTO T294-94 is a dynamic test done in a triaxial cell which determines a value, Resilient Modulus or M_R .

The Resilient Modulus value is an indication of a soil's resilience, or property by which the soil will recover from repeated stress such as that induced by pavement deflections from wheeled highway traffic over a long period of time. In general, highway subgrade materials which exhibit a high resilient modulus value are associated with pavements which maintain their integrity without requiring unusual maintenance measures.

The resilient modulus testing is accomplished by applying a sequence of several thousand pulsed loads to a 2.8" diameter soil sample, such as a Shelby Tube specimen. Tests done under this procedure will be "type II" tests, which are cohesive, rather than granular soils.

A soil which has residual deformation and substantial loss of sample length at the end of this tests will have a resilient modulus value which is low. A soil which recovers from these deformations to almost the original sample length which was measured at the start of the test will have a high resilient modulus value. The M_R value may be expressed in pounds per square inch (psi).

Geotechnical Engineers are able to use Resilient Modulus as a tool for highway design. Resilient Modulus may also be used as a tool to seek answers in the case of existing highways which exhibit pavement problems.

The INDoT laboratory procedure will permit you to run the resilient modulus tests and to determine resilient modulus value.

II. Equipment Required

A. MTS Load frame and load cell	(see photo #1)
B. Research Engineering Triaxial Cell	(see photo #2)
C. MTS Extensometers for strain measurements	(see photo #3)
D. Sample Preparation Tools	(see photo #4)
E. Vacuum Split Mold and Latex Membrane	(see photo #5)
F. Computer and ATS controller, MTS interface	

III. Prior Training and Experience

The Resilient Modulus test is a complex and sophisticated laboratory procedure. It is also, however, a very satisfying test to accomplish once you have learned the proper procedures. It will take approximately two weeks to learn this test from a previously trained operator. Once trained, you should expect to require assistance from your trainer for three to six months before you are fully comfortable with solo operation. You will need to set up and test as many as six trial samples

before you attempt to run a test for which you will report the results. You should also read the AASHTO T294-94 test standard.2

Before learning the particulars of the resilient modulus test procedures, you should be experienced and comfortable with the following laboratory procedures:

A. General soils classification and sample preparation from Shelby Tubes.
B. Unconfined Compression Tests.
C. Set up of samples in a triaxial cell.
D. Ability to Run and configure the MTS testing machine.
E. Experience with desktop computers and software setup.

All of the above can be learned through normal experiences in the soils laboratory at the Division of Materials and Tests. In the case of the MTS machine, some special training is required.

IV. MTS Dynamic Testing

You must be capable and comfortable with the MTS machine in dynamic mode before attempting to run any resilient modulus or other triaxial test.

The MTS machine will deliver 22,000 pounds in a ten inch piston movement in a fraction of a second. The piston of the MTS machine will reciprocate, back and forth, several times a second, all with 22,000 pounds of force. This machine can maim or kill you or your colleague. The MTS machine can destroy almost any piece of equipment in the laboratory before you can think to reach for the "stop" button. Be careful with this machine. Learn what it can do, and learn how to stop it. Before beginning to run cyclic tests with the MTS machine, you must learn the following:

A. Locate the 10 gpm pump. Learn how to turn it on and off, at low and high pressure.
B. Locate the three "emergency stop" buttons.
C. Install load cells and install the computer calibration files.
D. Unlock, raise, lower, and lock the crosshead.
E. Manually move the piston in "stroke control".
F. Set "limits" for maximum displacement and load. These are safety limits. Use Them!
G. Transition the machine from "stroke control" to "load control".
H. Run demonstration programs, in stroke control, at a frequency, displacement, and in a waveform determined by your instructor.

Refer to the MTS manuals and have an experienced MTS operator or MTS service technician help you with hands-on instruction with the MTS machine. Remember that in the case of MTS units, negative units indicate compression, and positive units equal tension.

The MTS machine has a few manual controls, but it is primarily controlled by the desktop computer which uses ATS software. The ATS controller includes pre-programmed test routines for most standard stress/strain tests as performed by INDoT including UU, CBR, and the Resilient Modulus test. Control parameters may be changed, but the templates are already configured to

follow the prescribed test protocols, and no change is necessary. All units and other values are already specified and the necessary calibrations are in place for automatic retrieval. The tests require no special configuration of the software prior to starting to run.

While learning how to operate the MTS machine, you should monitor the oscilloscope display which is available on a CRT "window" display via the ATS controller.

V. Assemble Equipment

The following pieces of smaller equipment and supplies are required to set up for the resilient modulus test using the RE triaxial cell. You should practice assembling the triaxial cell with a dummy sample after locating all of the following pieces:

A. MTS Load Frame
1. 2.5 kN (550 lbs.) load cell (photo #7)
2. MTS "spiral washers" and 1/2" x 20 tpi stud (photo #7)

B. RE Triaxial Cell
1. Triaxial Cell and Plexiglass Enclosure (photo #2)
2. Two MTS model #632.06H.20 extensometers to monitor axial deformation (photos #3)
3. Baseplate and bolts to attach cell to MTS load frame (photo #6)
4. MTS piston to Cell piston coupling flange, four bolts (photo #7)
5. Two signal cables for MTS extensometers (photo #8)
6. Air pressure line from laboratory compressor (photo #9)
7. Confinement air pressure transducer (photo #10)
8. Two "chopsticks" for removing the triaxial cell enclosure
9. Various hexagonal key wrenches required

C. Sample preparation equipment (photo #4)
1. Soil samples taken from Shelby tubes
2. Trim cradle and stand, trim mold
3. Spatulas, wire saws, and razor blades
4. Straight edge, square, protractor, and level
5. Vernier caliper for length measurement

D. Sample mounting equipment (photo #5)
1. Split vacuum mold
2. Latex membrane for 2.8" samples
3. "O" rings to retain membrane
4. Vacuum pump
5. Various spacers to adjust height of sample
6. Dummy sample, 2.8" x 5.5" red plastic

VI. Preparation of Triaxial Sample

You should first practice sample set up and in fact, the running of complete tests, while using the dummy sample. The set up procedure would be the same, with the exception of sample trimming.

A. Log the sample to be tested.

B. Trim and square the sample to a length approximately twice the diameter, or 5.6", and record length, diameter, and mass.

C. Use some sample trimmings for determination of water content.

D. Record these values on the proper laboratory form, and also enter these values into an ATS specimen computer file for resilient modulus, "T294.SPC".

E. Work carefully, but quickly, to avoid loss of moisture in the soil sample.

VII. Set up the Sample in the Cell

A. Work with the sample with the triaxial cell on the laboratory bench.

B. Remove the triaxial cell enclosure, and raise and lock the cell piston to maximum clearance, using the locking collar shown in photo #11.4.

C. Install some plastic spacer plates to buffer the length of the specimen to about 6.0". These spacers should be fixed to the cell platens with waterproof tape. Fit an "O" ring onto both the top and bottom platen.

D. Fit a latex membrane over the split vacuum mold, as in photo #5.

E. Apply a vacuum to the mold and fit the sample into the membrane.

F. Place the mold, membrane, and sample into the cell between the platens while still drawing vacuum.

G. Unlock the cell piston and lower the top platen into contact with the sample. Once again, lock the cell piston.

H. Roll the ends of the membrane onto both the top and bottom platen, and secure with the "O" rings, as in photo #12.

I. Release the vacuum, then separate and remove the split mold.

J.Install the plexiglass enclosure and lock the safety clasps into place at the top,

K. Open all drain line valves from the sample to the atmosphere.

L. Install the two MTS extensometers and adjust the bearing plate, shown in photo #11.3, such that these two instruments are approximately midrange.

VIII. Install the Cell into the MTS Load Frame

A. Fix the baseplate to the MTS load frame, as in photo #13.

B. Raise the MTS crosshead to allow adequate clearance for the triaxial cell.

C. Ensure that the proper load cell, 550 lbs. is installed and connected to the signal cable.

D. Ensure that the upper half of the connecting flange is installed.

E. Place the cell onto the cell baseplate which is in the MTS load frame.

F. With the MTS piston in approximately midrange, lower the MTS crosshead such that about 1.0 cm separates the two halves of the connecting flanges.

G. Using the ATS controller in STROKE control, lower the MTS piston to fit the two halves of the flanges together, as in photo #14. Monitor the load which is applied to the LOCKED PISTON upon contact. A load of approximately 20-50 pounds is quite acceptable.

H. Adjust as necessary, then install the four bolts which secure the two halves of the connecting flange, again as in photo #14.

I. Connect the air pressure line, the pressure transducer, and the extensometer cables.

IX. Prepare for Testing

During the time when the sample is prepared and the cell is coupled to the MTS machine, the MTS pump should be turned on in order to warm the hydraulic system.

A. Zero the two MTS extensometers, manually using the software of the ATS controller.

B. Ensure that MTS load and stroke limits are set which will shutdown the system if the loads and displacements exceed the capacity of the triaxial cell. Like other information in the ATS templates for the resilient modulus test, these values have been pre-entered.

C. Select type II tests from the ATS Menu for Resilient Modulus. Proper default values have already been entered for all aspects of cycling the sample and monitoring the data. These values may be viewed in the pop-up menus of the ATS test sequence template. Refer to the ATS-MTS manual for background information on how to set such parameters. We repeat, however, that test parameters are set, and do not need to be changed.

D. Unlock the piston of the triaxial cell. This is important.

X. Run the Resilient Modulus Test Sequence

A. Be certain that you have unlocked the piston of the triaxial cell.

B. Select "start test" in the pop-up menu of the ATS controller.

C. The following sequence will now occur, automatically and quite quickly:

1. The MTS machine will change command mode to LOAD CONTROL.

2. The required seating load will be applied to the specimen.

3. A confining pressure of 41 kPa (6 psi) will be applied to the triaxial cell. You will hear the air flow into the cell.

4. A "preconditioning" of 1000, one second load cycles will be applied.

5. The system will automatically transition into the recorded test sequence, which is 100 cycles each in 15 different steps. The system will apply 100 cycles of load at each of 2, 4, 6, 8, and 10 psi of deviator stress, all at 6 psi confinement pressure. These same five applications of load will then be repeated, but at 3 psi confinement. You will hear the air pressure change. Lastly, the confinement pressure will drop to 0 psi (gauge), and the same five loads will be repeated again. This is a total of 2500 pulsed load applications, but the test proper takes only about 45 minutes from start to finish.

D. During the conduct of the automated, 15 step sequence of tests, it is possible to monitor the readings from the load cell, which indicates the stress pulses, and from the two #632.06H.20 extensometers, which measure the changes in length of the sample. It is also HIGHLY RECOMMENDED that you create a window of the ATS oscilloscope. A normal haversine waveform output is the best indication that the test is proceeding properly.

E. When the monitor indicates that the test is complete, the data will have been collected in your specified test file. A resilient modulus value and plot, in psi may be printed.

F. In the event that the sample deforms to a shorter than expected length (strain reduction

of 5%) or fails altogether, then the test procedure will halt, even if all 15 steps have not been completed. A test thus halted will give a complete test result, which will be an unusually low resilient modulus value, perhaps less than 5000 psi. This is a reportable result, even though the entire test sequence was not completed.

XI. Trouble

A. In the event that the MTS machine begins to behave erratically, you should not hesitate to push the EMERGENCY STOP button. The worst that will happen is that you will have to repeat the test with a new specimen. If you hesitate to take immediate emergency action, you run the risk of destroying the triaxial cell, load cell, and extensometers. It is a simple and quick matter to do $20,000.00 of damage in only a few seconds.

B. A more frustrating problem is the case when the test will not start, or stops immediately after starting a test. This is almost always the case of being "out of bounds" with limit ranges. In this case, the extensometers must be zeroed, the load applied or maximum load level changed, or the crosshead relocated. Remember, there are many safeguards built into this powerful testing machine. No doubt, you have inadvertently violated a safety limit. Be patient, review all parameters, and you will find your problem.

XII. After the Test

A. Once the monitor indicates that the test is complete or otherwise halted, you should first print the test result.

B. With results in hand, lock the cell piston in place and shut off the MTS hydraulic system.

C. The cell may now be uncoupled, the crosshead raised, and the sample removed for a manual check of the length. At this point, you are ready to proceed with another sample, or to clean and store the resilient modulus equipment.

XIII. Resources

A. AASHTO T294-94, Standard Method of Test for Resilient Modulus.

B. MTS operators manuals for 810 Test System.

C. ATS-MTS digital control system, MTS Controller Manuals.

D. SHRP Equipment Corp. (ATS Software), Tel: 510 231 9598 Fax: 510 934 4910

Jorge B. Sousa, PhD.
SHRP Equipment Corp.
724 Laurel Drive
Walnut Creek, CA 94596

E. MTS Help, Tel: 612 937 4453

F. Ross A. Duckworth, Tel: 215 413 9001 Fax: 215 413 9004

Ross A. Duckworth
P.O. Box 809
Philadelphia, PA 19105-0809

duckwort@ecn.purdue.edu

Appendices:

A Photographs 1-15

B Typical Test Results

C AASHTO T294-94 Test Standard

D MTS Soil Resilient Modulus Manual

Appendix A

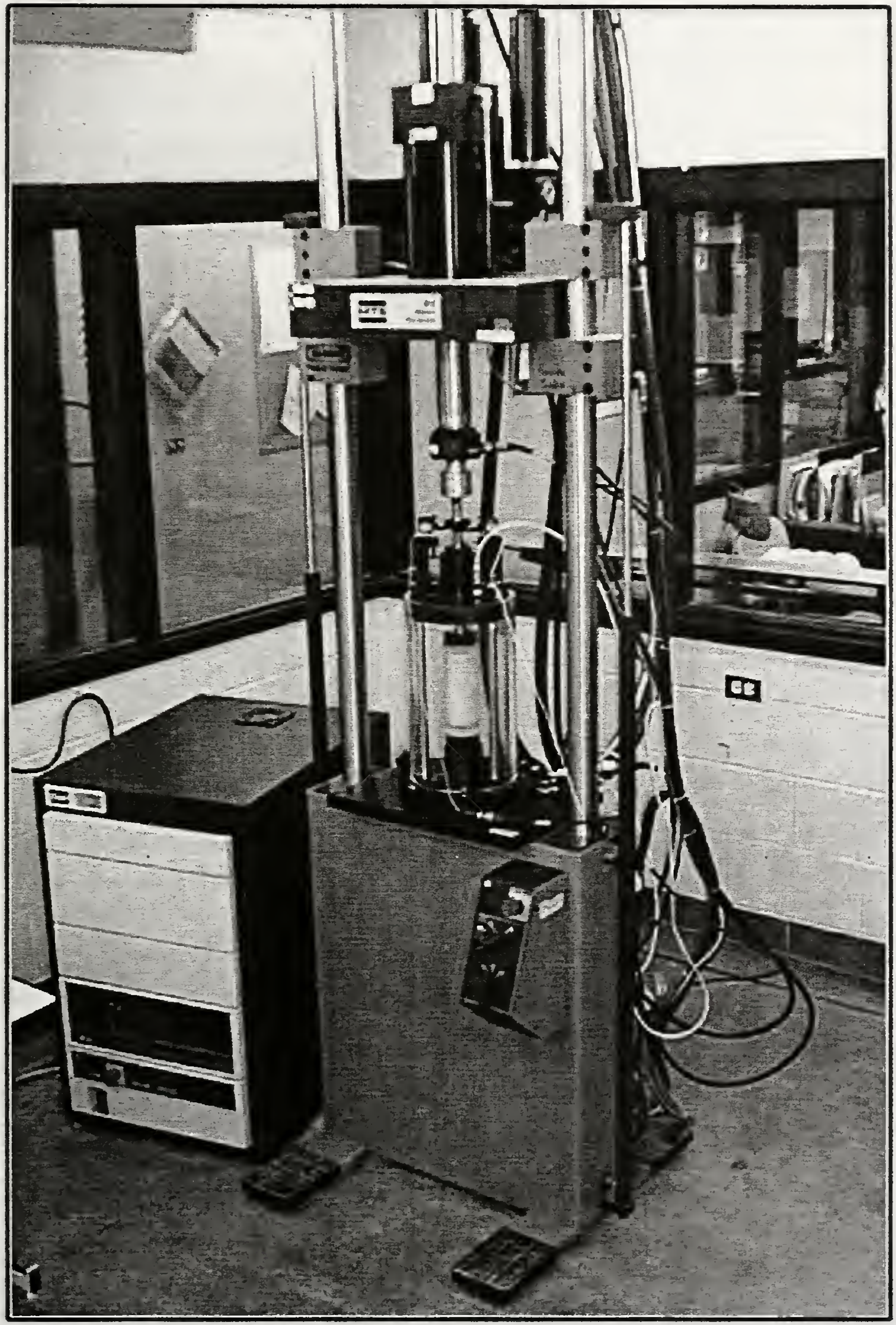


Photo #1. MTS Load Frame and Load Cell

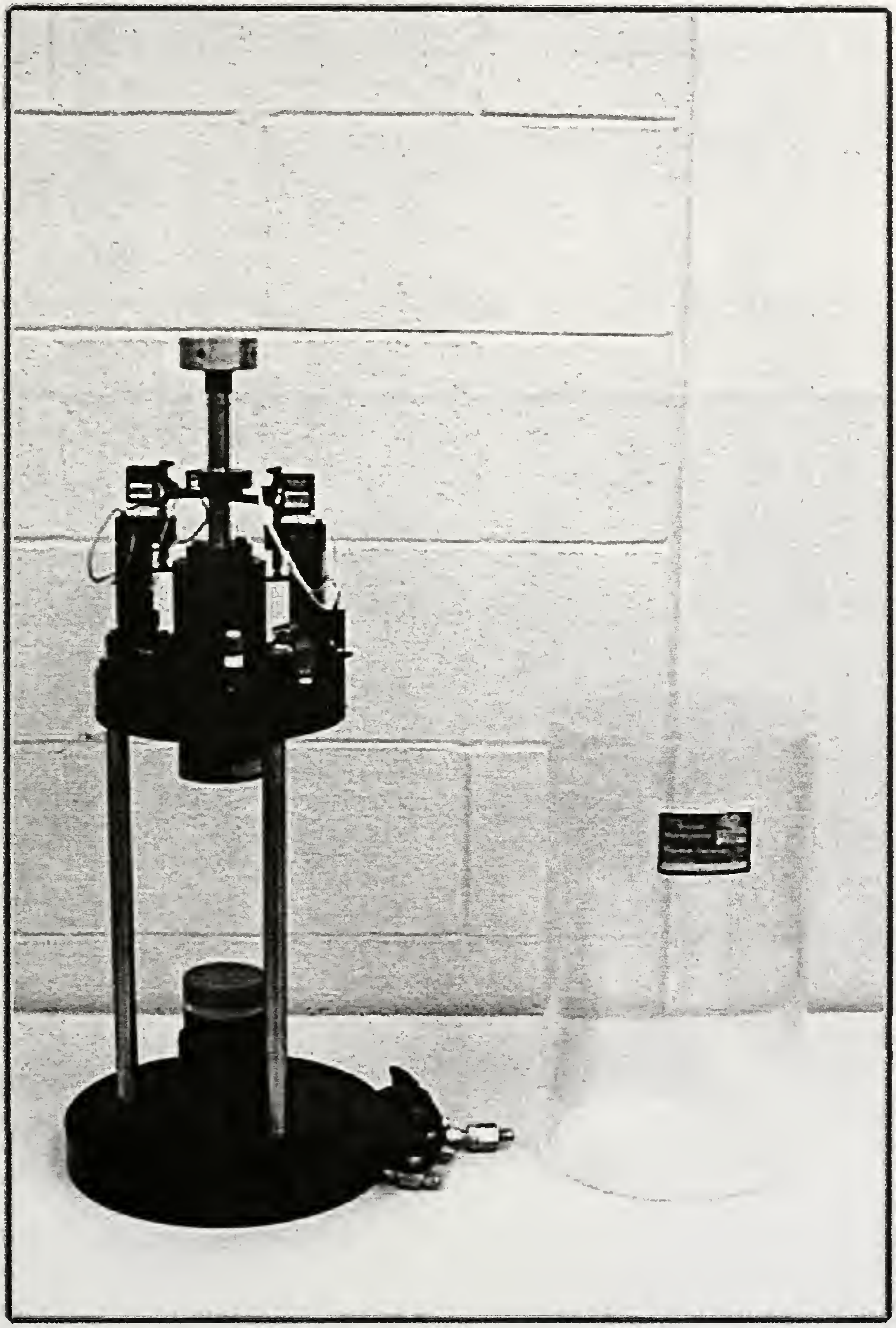


Photo #2. Research Engineering Triaxial Cell

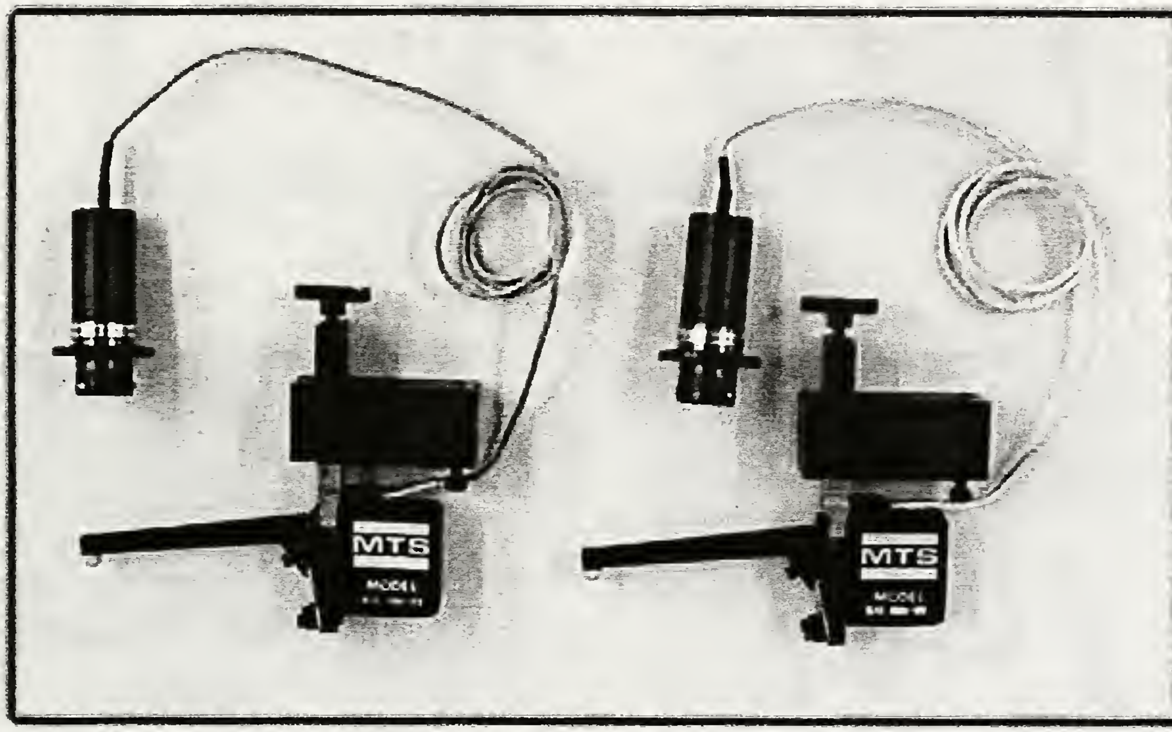
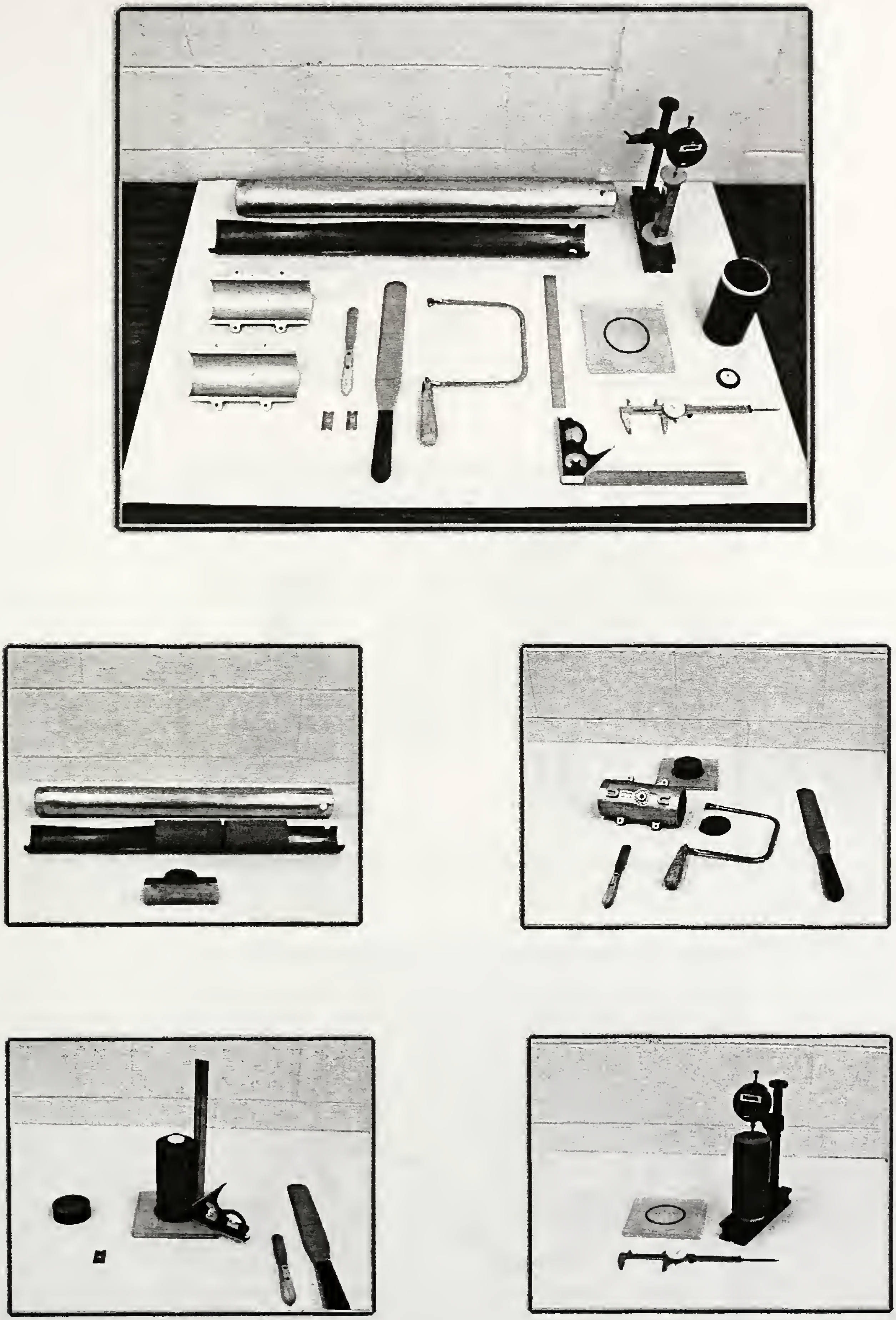
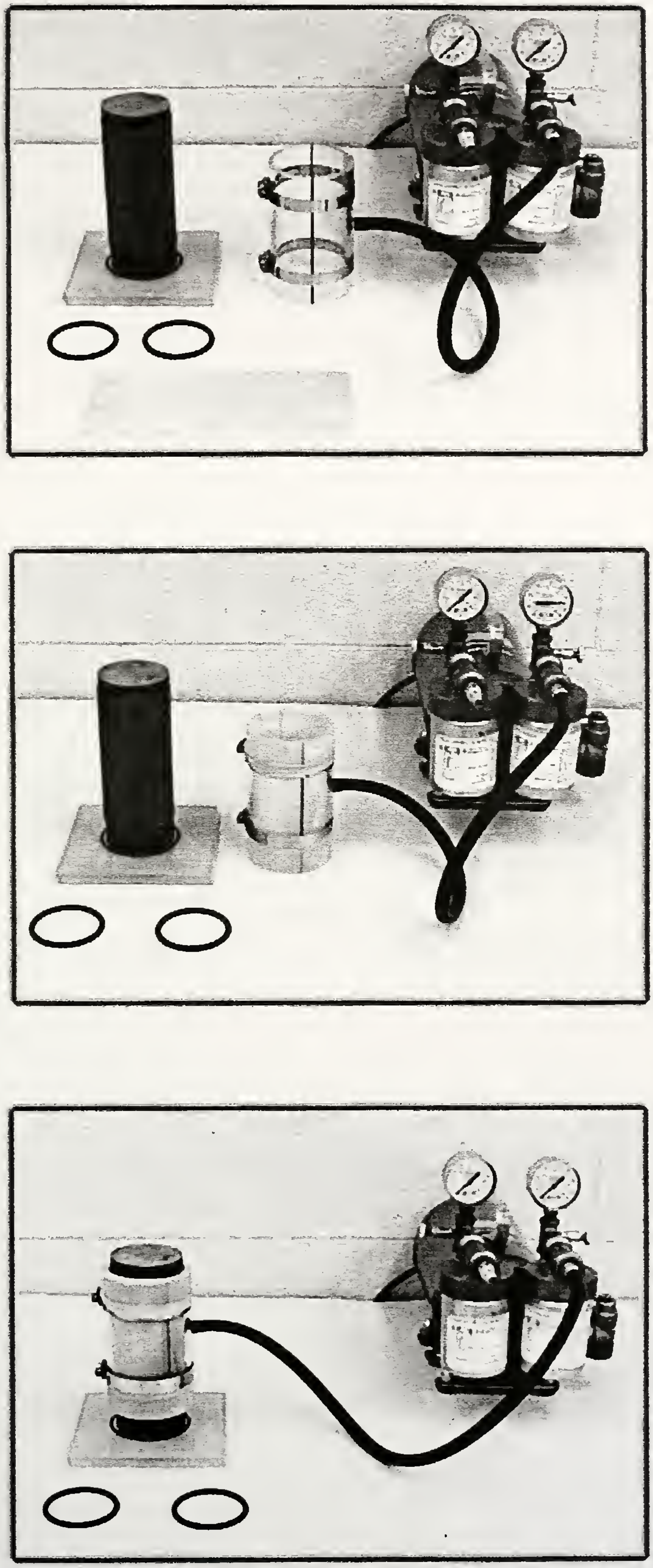


Photo #3. MTS Extensometers for Strain Measurements



Photos #4. Sample Preparation Tools



Photos #5. Vacuum Split Mold and Latex Membrane

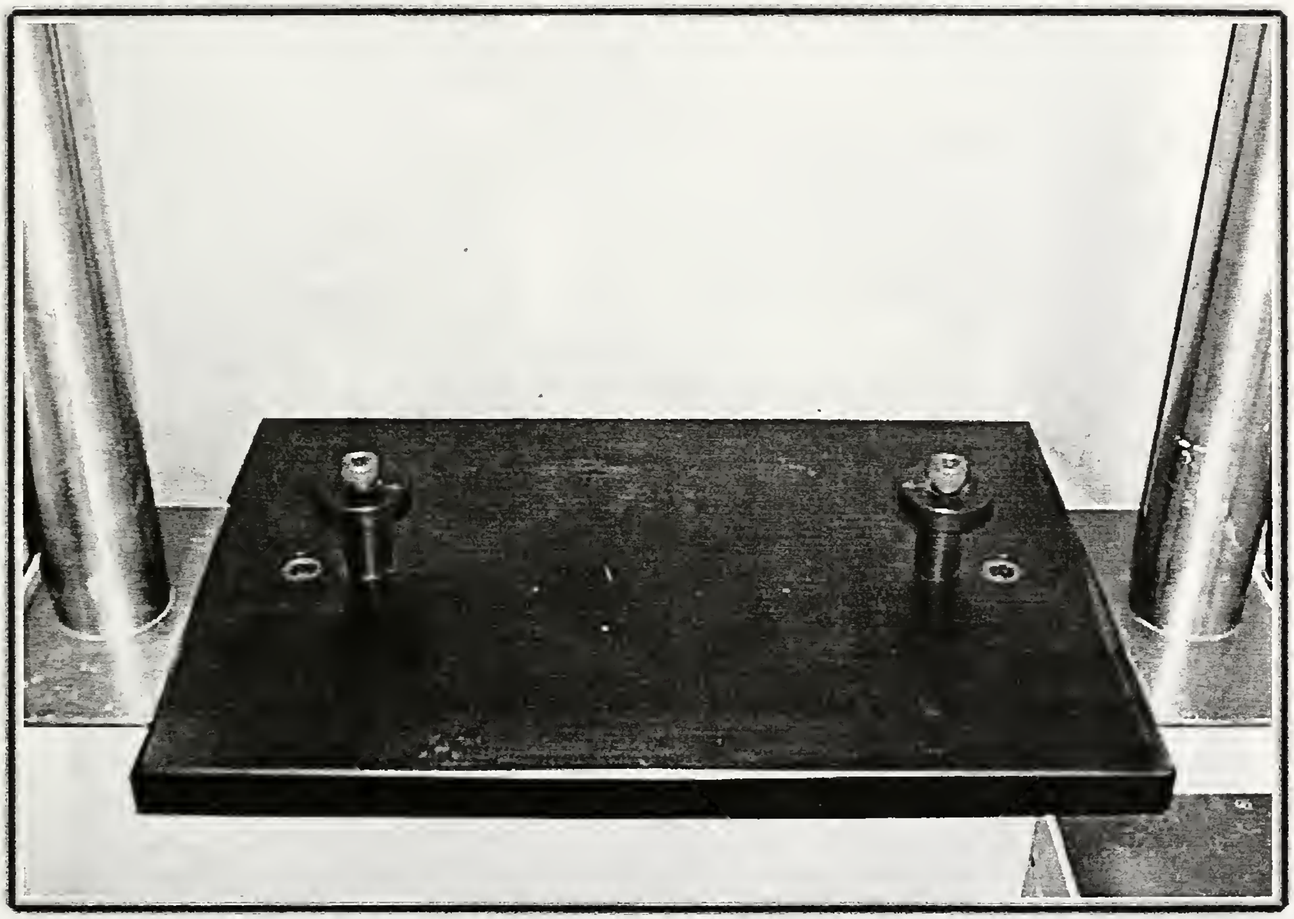


Photo #6. Baseplate to Attach Cell to MTS Load Frame

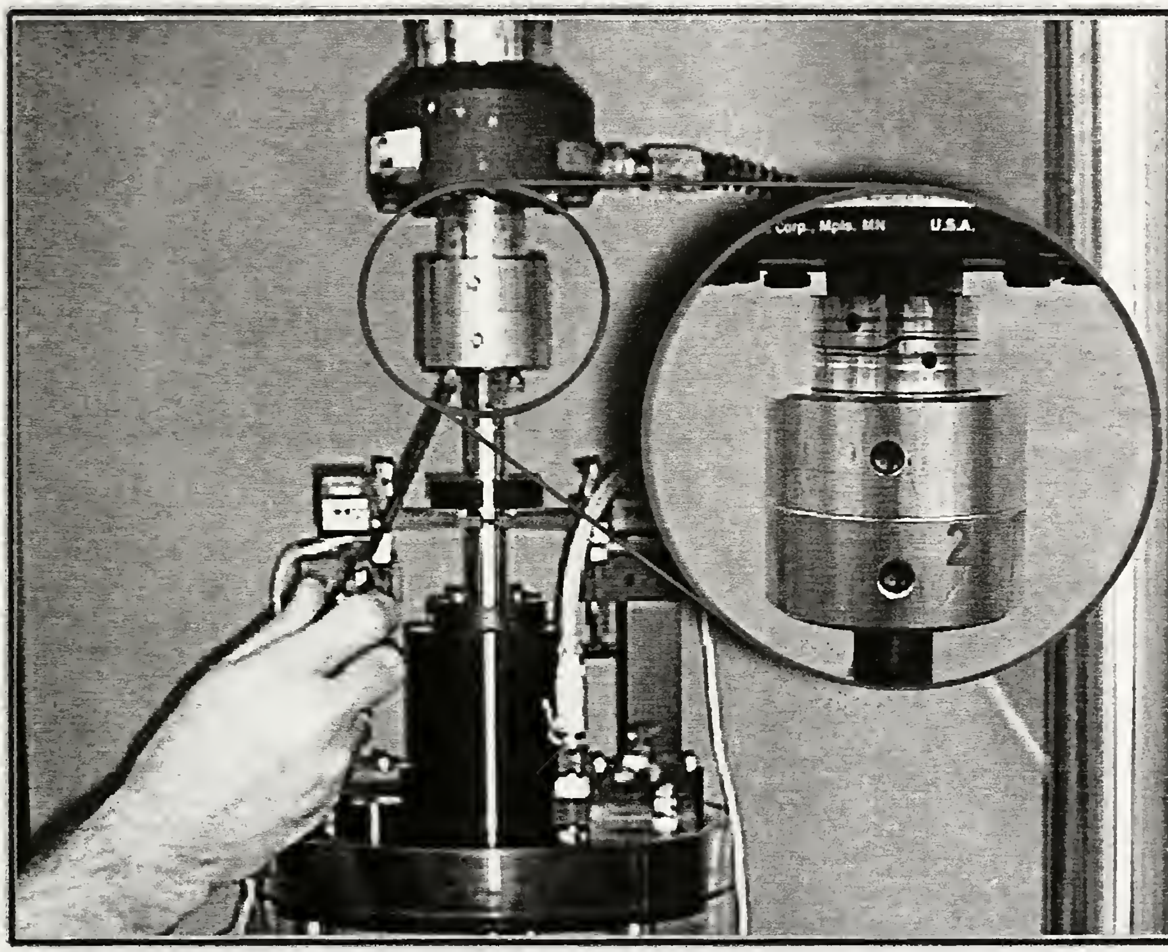


Photo #7. MTS Piston Fit to Cell Piston

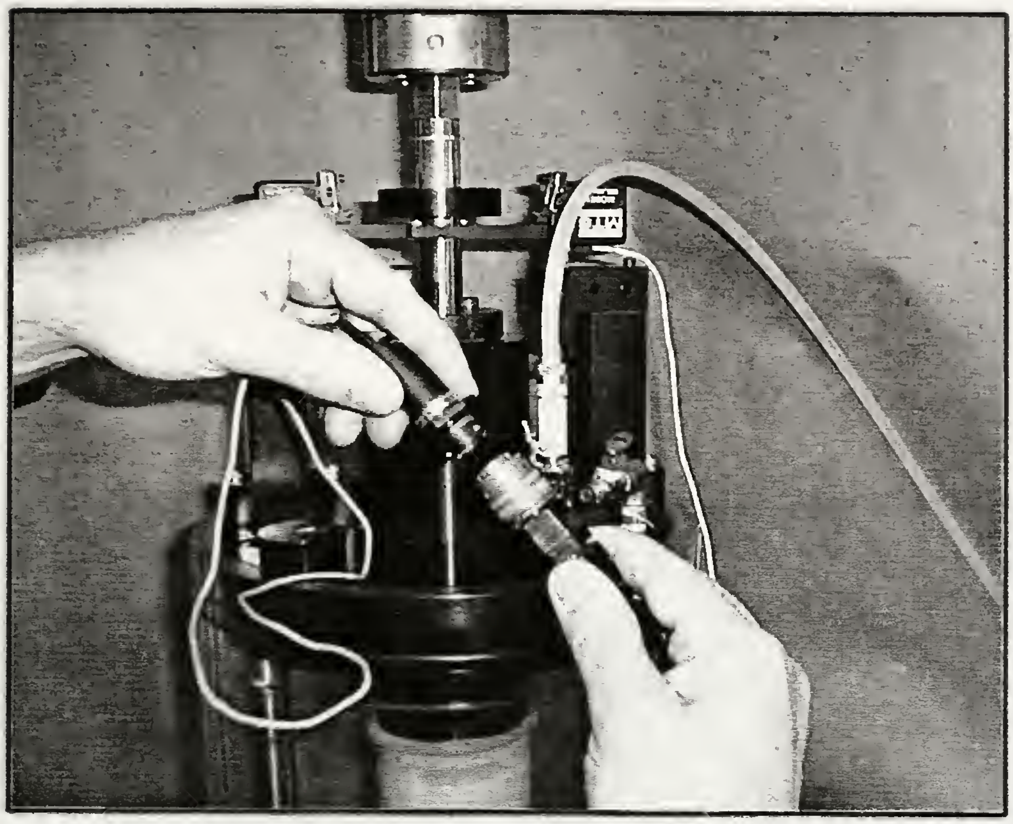


Photo #8. Cables for Extensometers

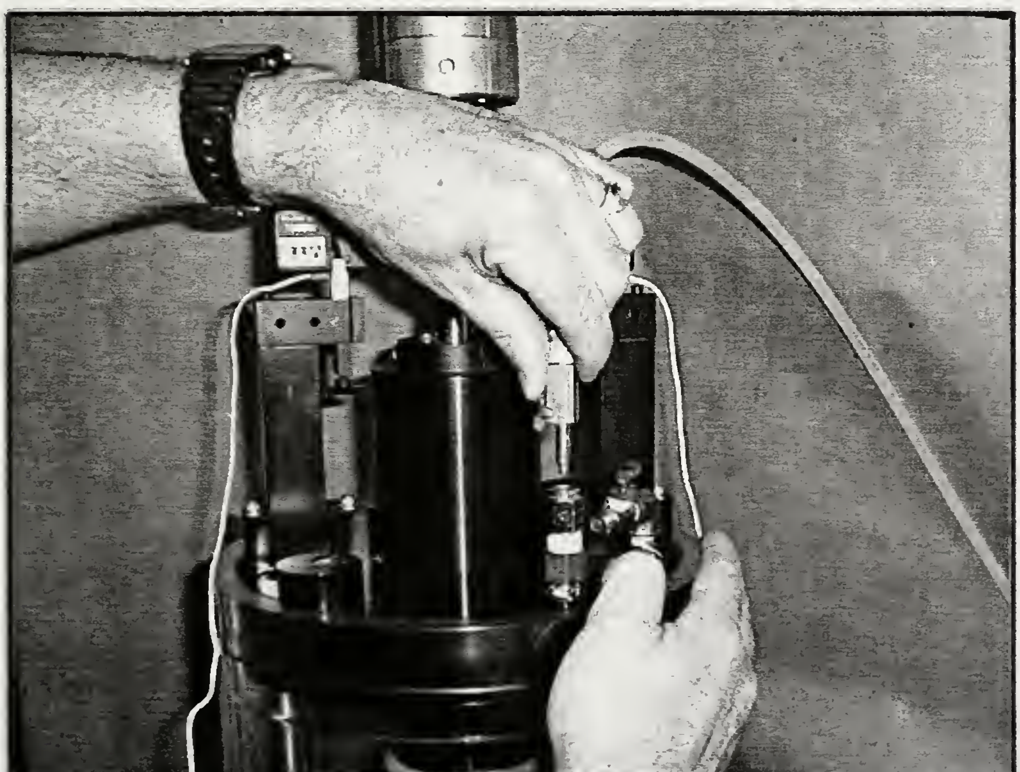


Photo #9. Air Pressure Line from Compressor

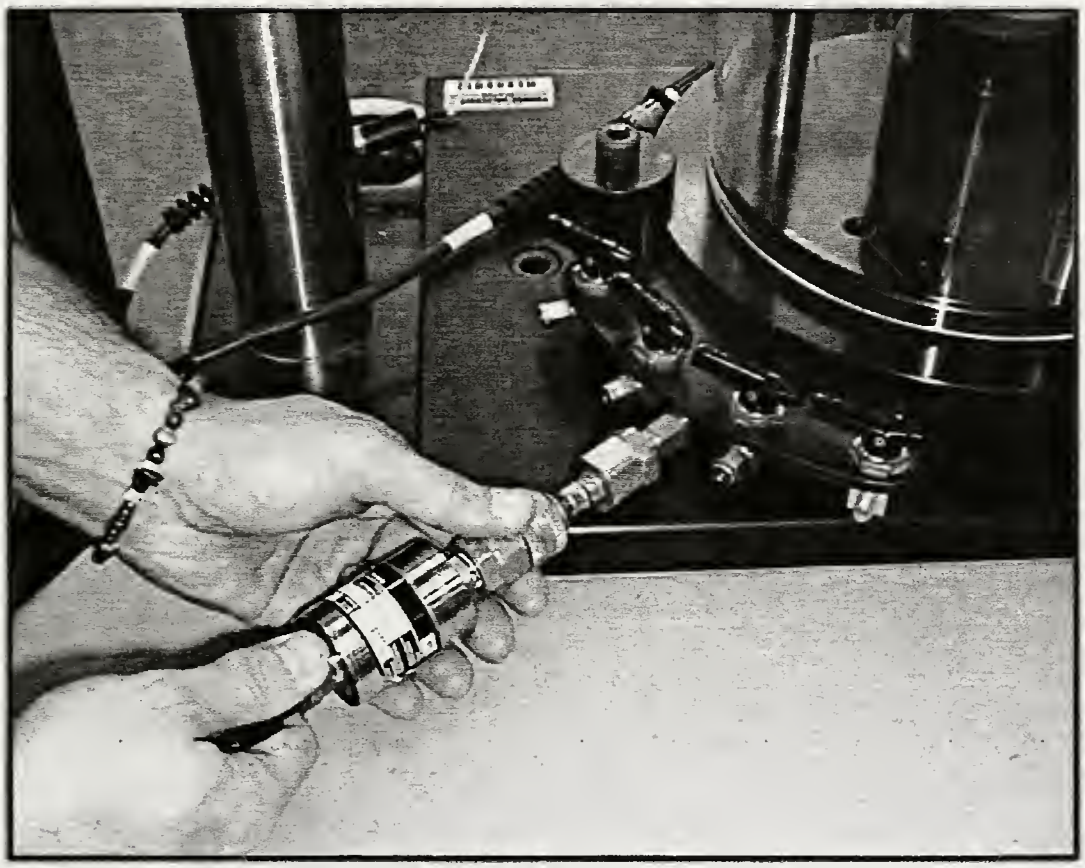


Photo #10. Confinement Air Pressure Transducer

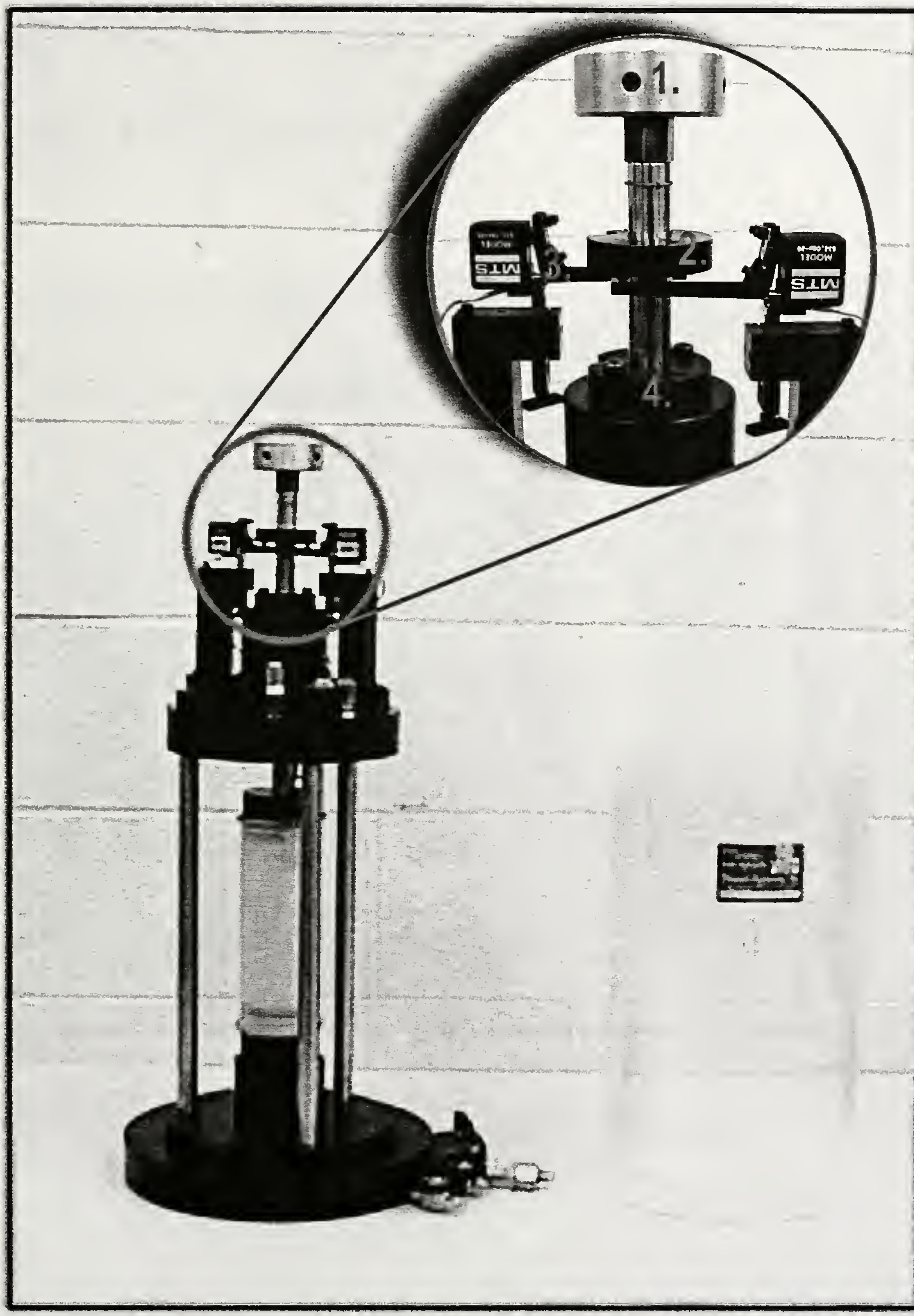


Photo #11. Cell Piston Locked for Placement into Load Frame

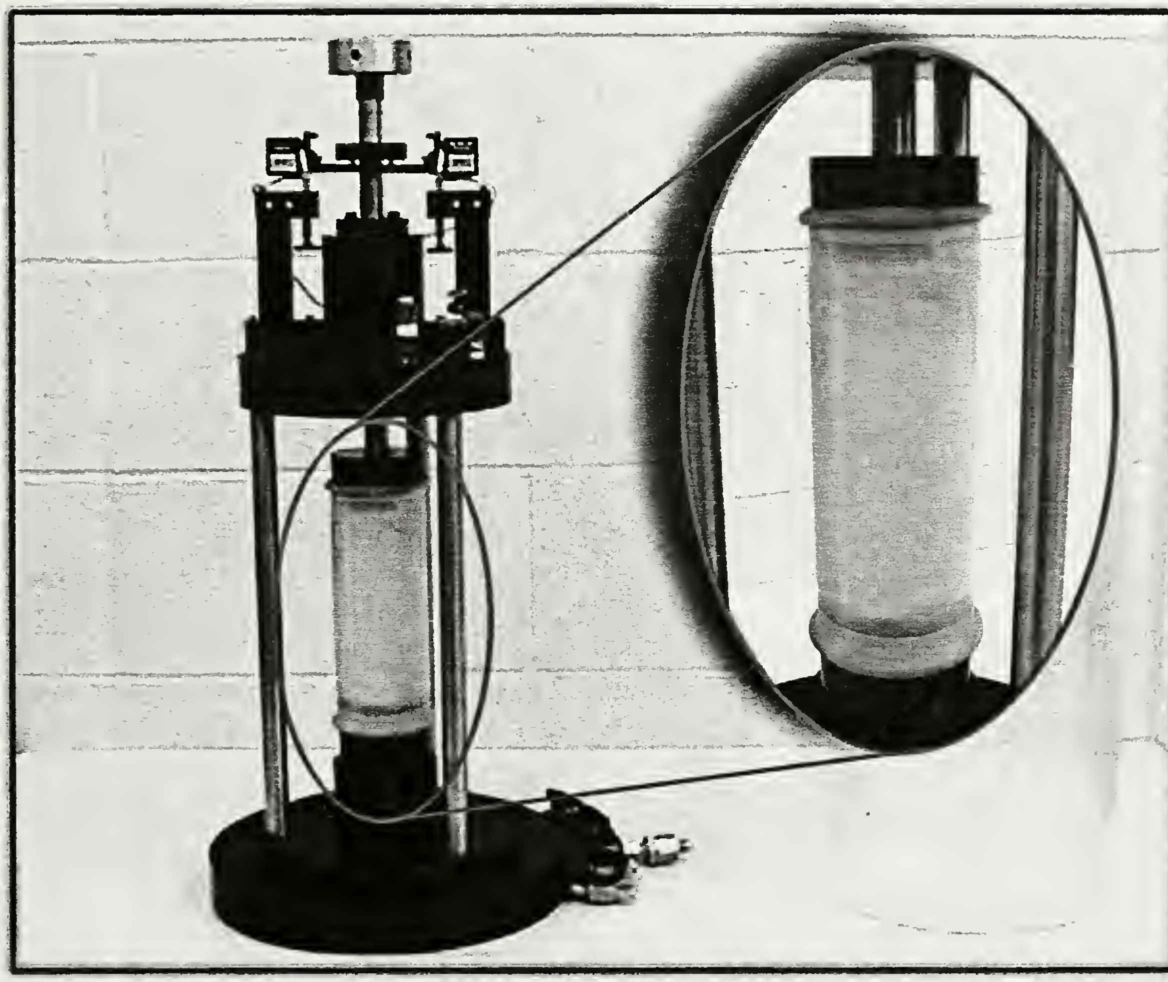


Photo #12. Membrane Properly Fitted

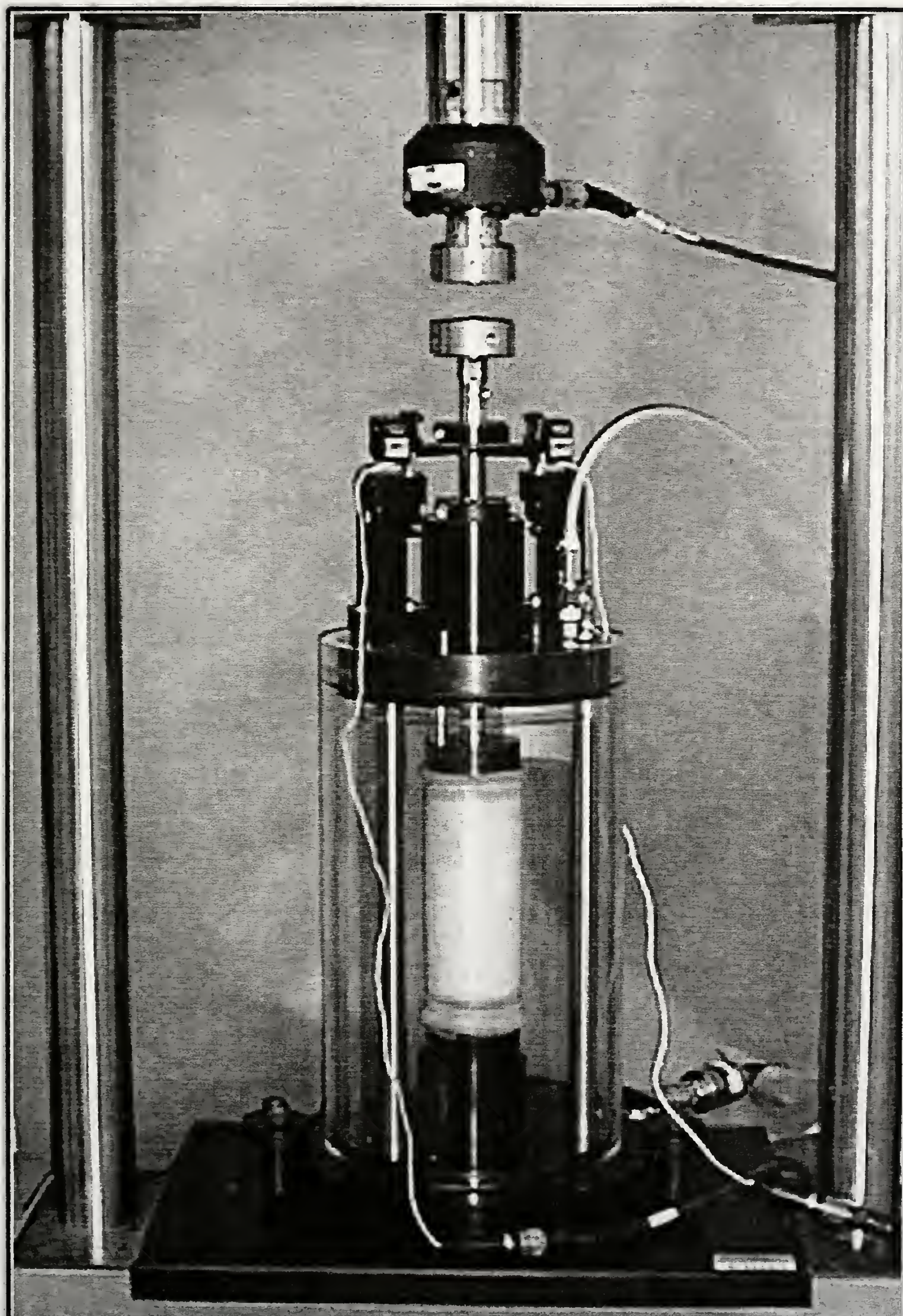


Photo #13. Base Plate and Cell Fixed to Load Frame

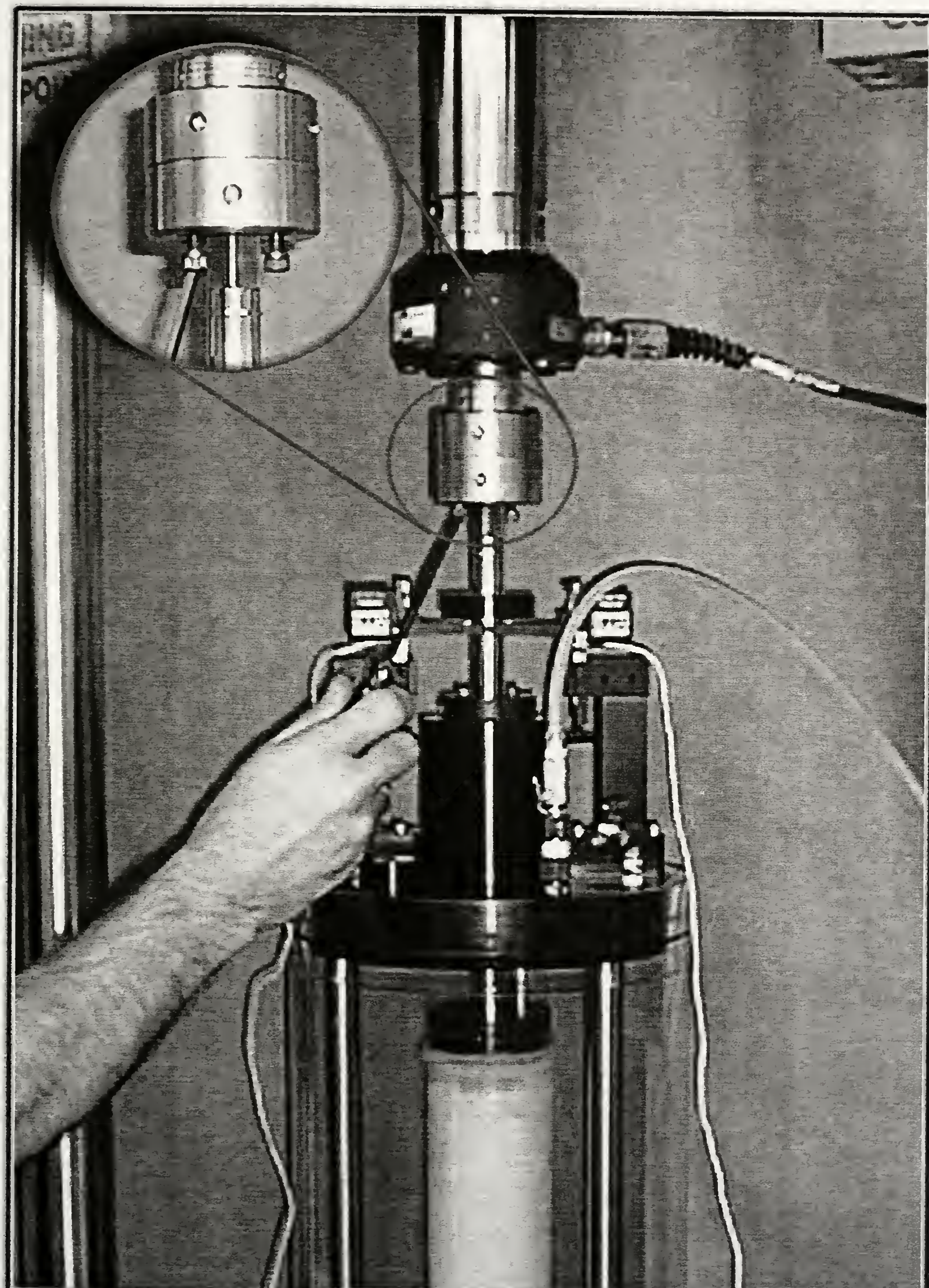
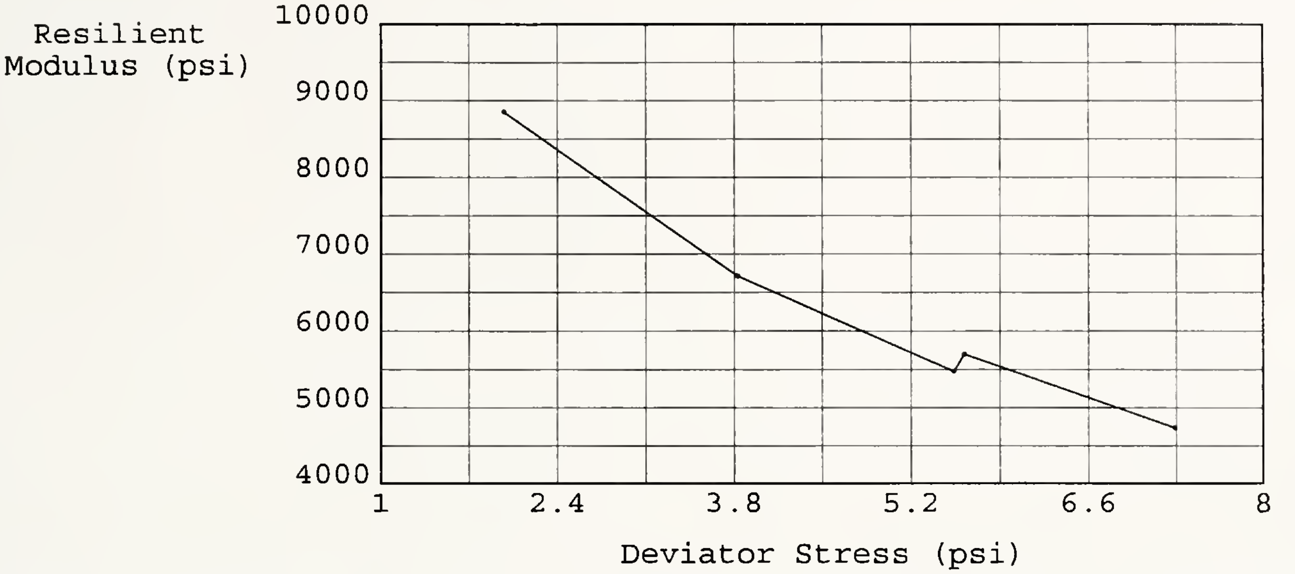


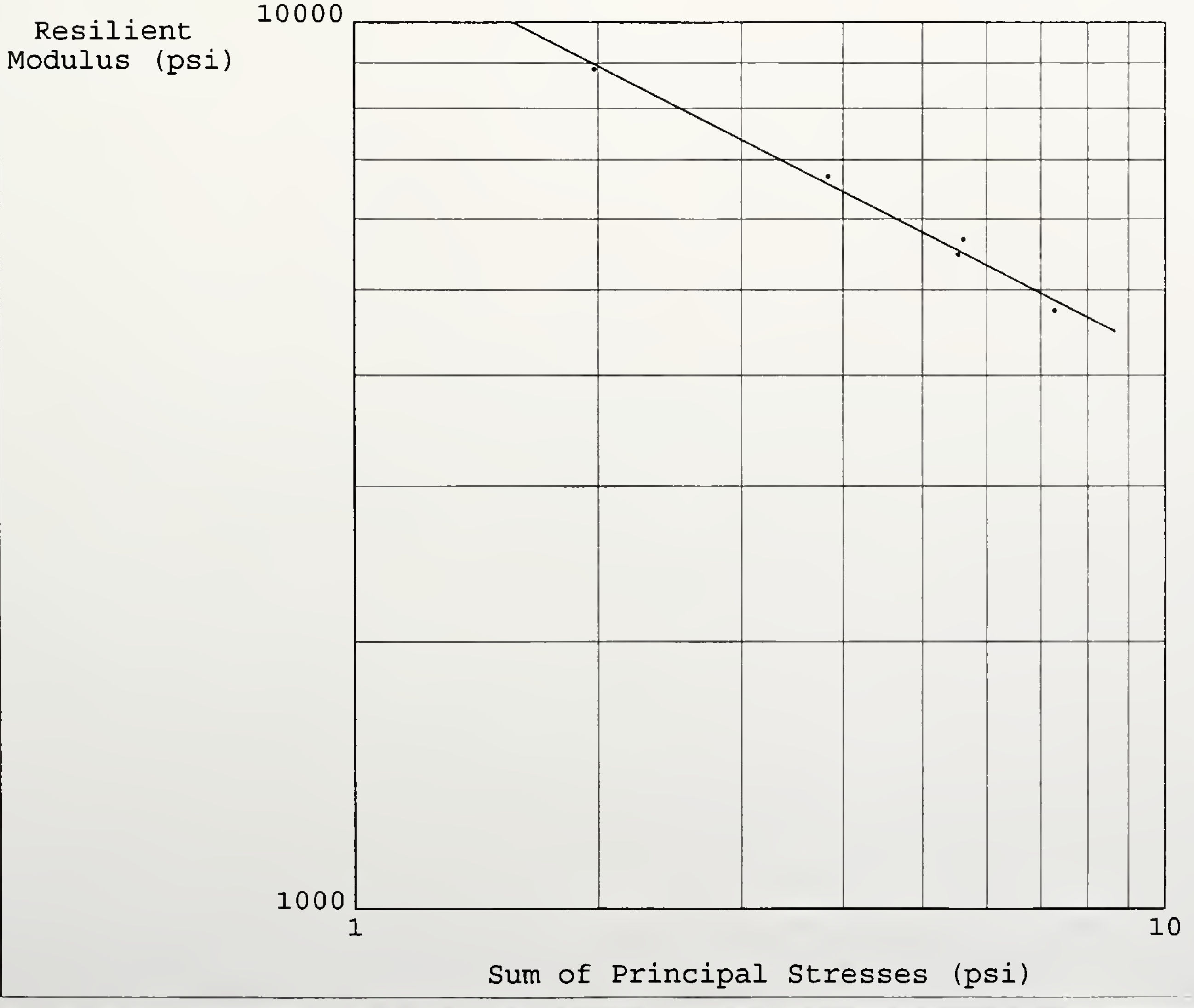
Photo #14. Fitting Piston for Loading

SHRP Equipment Corporation

ATS Report

RB20P14X.DAT --- k1 = 12359.8 k2 = -0.468337





RB20P14X.DAT

SHRP_Equipment_Corporation
Automatic_Testing_System_v.3.12

AA274_RESULTS

RESIL_MOD_DATA

Nom._d.	Avg._	Res._stress	Res._axial_strain	Res._axial_mo
psi	psi	psi	none	psi
0	0	5.53677	0.0010111	5479.22
0	0	1.97928	0.000223505	8855.78
0	0	3.83271	0.000570976	6712.58
0	0	5.62026	0.000985987	5700.13
0	0	7.28988	0.00153745	4741.54

TOTAL_DATA_LINES
5

Standard Method of Test
for

Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils—SHRP Protocol P46

AASHTO DESIGNATION: T 294-94

1. SCOPE

1.1 This method covers procedures for preparing and testing unbound granular base/subbase materials and subgrade soils for determination of resilient modulus under specified conditions representing stress states beneath flexible and rigid pavements subjected to moving wheel loads.

1.2 The methods described are applicable to: undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of unbound base and subbase and subgrade soils prepared for testing by compaction in the laboratory.

1.3 The value of resilient modulus (M_r) determined from this procedure is a measure of the elastic modulus of unbound base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.

1.4 Resilient modulus (M_r) values can be used with structural response analysis models to calculate pavement structural response to wheel loads, and with pavement design procedures to design pavement structures.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

- M 145 The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- T 11 Amount of Material Finer than 0.075-mm (No. 200 sieve) in Aggregate
- T 27 Sieve Analysis of Coarse and Fine Aggregates
- T 88 Particle Size Analysis of Soils
- T 89 Determining the Liquid Limit of Soils
- T 90 Determining the Plastic Limit and Plasticity Index of Soils
- T 99 The Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-In.) Drop
- T 100 Specific Gravity of Soils
- T 233 Density of Soil-in-Place by Block, Chunk or Core Sampling
- T 265 Laboratory Determination of Moisture Content of Soils

3. SUMMARY OF TEST METHOD

3.1 A repeated axial deviator stress of fixed magnitude, load duration (0.1 second), and cycle duration (1 second) is applied to a cylindrical test specimen. During testing, the specimen is subjected to a dynamic deviator stress and a static confining stress provided by means of a triaxial pressure chamber. The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus.

4. SIGNIFICANCE AND USE

4.1 The resilient modulus test provides a basic constitutive relationship between stress and deformation of pavement construction materials for use in structural analysis of layered pavement systems.

4.2 The resilient modulus test provides a means of characterizing pavement construction materials, including subgrade soils under a variety of conditions (i.e. moisture, density, etc.) and stress states that simulate the conditions in pavements subjected to moving wheel loads.

5. BASIC DEFINITIONS

5.1 *Description of Symbols:*

5.1.1 S_1 is the total axial stress (major principal stress).

5.1.2 S_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor principal stress).

5.1.3 $S_d = S_1 - S_3$ is the repeated axial deviator stress for this procedure, and is the difference between the major and minor principal stresses in a triaxial test.

5.1.4 e_1 is the total axial deformation due to S_d.

5.1.5 e_r is the resilient (recovered) axial deformation due to S_d.

5.1.6 $M_r = S_d/e_r$ is defined as the resilient modulus.

5.1.7 Load duration is the time interval the specimen is subjected to a deviator stress.

5.1.8 Cycle duration is the time interval between successive applications of a deviator stress.

5.1.9 $Y_d = GY_w / 1 + (wG/S)$

where:

Y_d = unit mass of dry soil, kilograms per cubic meter (pounds per cubic foot)

G = specific gravity of soil solids, dimensionless,

w = moisture content of soil, (percent),

S = degree of saturation (percent), and

Y_w = unit mass of water, kilograms per cubic meter (pounds per cubic foot) and may be assumed to be 1000 kilograms per cubic meter (62.4 pounds per cubic foot).

NOTE 1—Both w and S must be expressed as numbers (e.g., 20 percent is 20), and shall be reported as numbers.

5.2 *Terminology:*

5.2.1 *Layer*—That part of the pavement produced with similar material and placed with similar equipment and techniques. The material within a particular layer is assumed to be homogeneous.

5.2.2 *Sample*—A representative portion of material from one or more pavement layers.

5.2.3 *Bulk Sample*—That part of the pavement material that is removed from an unbound base or subbase layer or from the subgrade. The material from one layer should *never* be mixed with the material from another layer—even if there is less than the desired amount to perform the specified tests.

5.2.4 *Test Sample*—That part of the unbound base or subbase layer or subgrade which is prepared and used for the specified test. The quantity of the test sample may be the same but will usually be less than the bulk sample.

5.2.5 *Test Specimen*—For the purpose of this procedure, a test specimen is defined as (i) that part of the thin-walled tube sample of the subgrade which is used for the specified tests and (ii) that part of the test sample of unbound granular base or subbase materials or untreated subgrade soils which is remolded to the specified moisture and density condition by recompaction in the laboratory.

5.2.6 *Unbound Granular Base and Subbase Materials*—These include soil-aggregate mixtures and naturally occurring materials used in *each* layer of base or subbase. No binding or stabilizing agent is used to prepare unbound granular base or subbase layers.

5.2.7 *Subgrade*—These include natural foundation or embankment soils which are prepared and compacted before the placement of subbase and/or base layers.

5.2.8 *Material Type 1*—For the purposes of this procedure (resilient modulus tests), *Material Type 1* includes: (i) all unbound granular base and subbase material, and (ii) all untreated subgrade soils which meet the criteria of less than 70 percent passing the 2.00-mm (No. 10) sieve and 20 percent maximum passing the 0.075-mm (No. 200) sieve. Testing parameters used for Type 1 unbound materials are different from those specified for Material Type 2. Type 1 will always include AASHTO classification A-1-a soils and may include A-1-b, A-2, or A-3 soils.

5.2.9 *Material Type 2*—For the purpose of this procedure (resilient modulus tests), *Material Type 2* includes all untreated subgrade soils not meeting the criteria given above in Section 5.2.8 (ii). Generally, thin-walled tube samples of untreated subgrade soils fall in this Type 2 category. Type 2 will always include AASHTO classification A-4, A-5, A-6, and A-7 soils and may include A-1-b, A-2, and A-3 soils.

5.2.10 *Resilient Modulus of Unbound Materials*—The modulus of an unbound material is determined by repeated load triaxial compression tests on test specimens of the unbound material samples. Resilient modulus (M_r) is the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain.

6. APPARATUS

6.1 *Triaxial Pressure Chamber*—The pressure chamber is used to contain the test specimen and the confining fluid during the test. A triaxial chamber suitable for use in resilient testing of soils is shown in Figure 1. The chamber is similar to most standard triaxial cells, but is somewhat larger to accommodate the *internally* mounted load measuring device, and includes additional outlets for the electrical leads from the load measuring device. The deformation is measured *externally* with two spring loaded LVDT's as shown in Figure 1. Air shall be used in the triaxial chamber as the confining fluid.

6.2 *Loading Device:*

6.2.1 The external loading device must be capable of providing variable magnitudes of repeated loads for fixed cycles of load and rest period. A closed-loop electro-hydraulic system is required for this procedure.

6.2.2 A load duration of 0.1 seconds and cycle duration of 1 second is required. A haversine shaped stress pulse form shall be used.

6.3 Load and Specimen Response Measuring Equipment:

6.3.1 The axial load measuring device should be an electronic load cell and will be located between the specimen cap and the loading piston as shown in Figure 1. The following load cell capacities are recommended:

Sample Diameter in mm (in.)	Maximum Load Capacity
71 (2.8)	445 N (100 lb)
102 (4.0)	2670 N (600 lb)
152 (6.0)	6230 N (1400 lb)

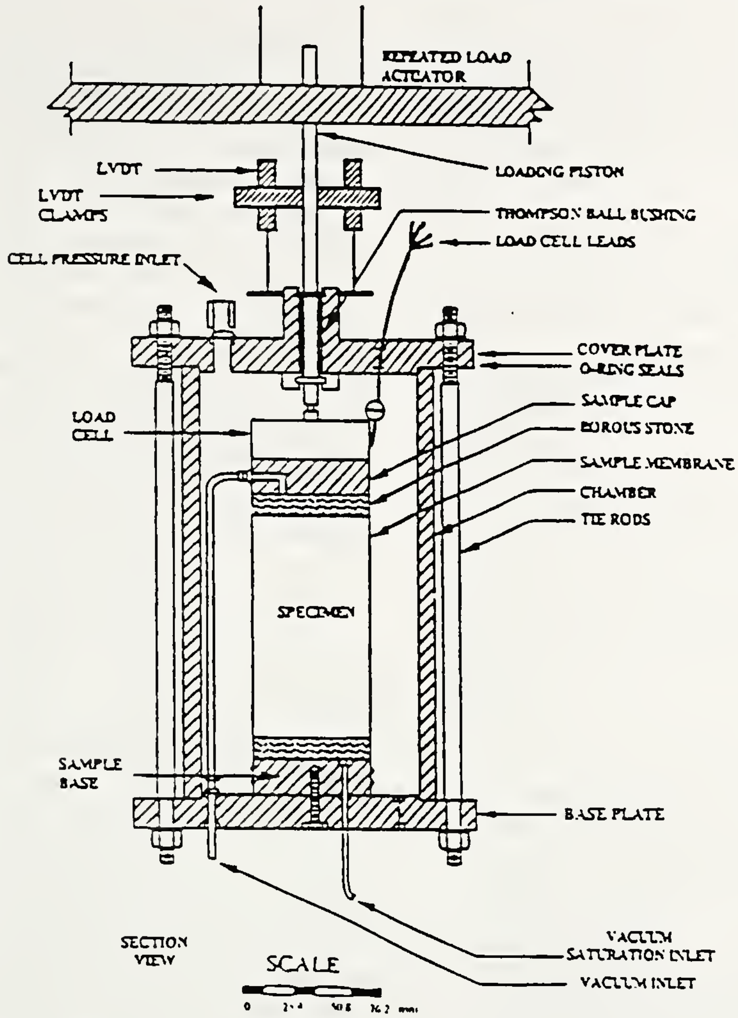
6.3.2 Test chamber pressures shall be monitored with conventional pressure gages, manometers or pressure transducers accurate to 1 kPa (0.1 psi).

6.3.3 *Axial Deformation*—Measuring equipment for all materials shall consist of two Linear Variable Differential Transducers (LVDT's) clamped to the piston rod outside the test chamber as shown in Figure 1. Spring-loaded LVDT's are required. The following LVDT ranges are recommended:

Sample Diameter in mm (in.)	Range
71 (2.8)	± 1.3 mm (0.05 in.)
102 (4.0)	± 2.5 mm (0.1 in.)
152 (6.0)	± 6.4 mm (0.25 in.)

All the LVDT's shall meet the following specifications:

Linearity	±25 percent of full scale
Repeatability	±1 percent of full scale
Minimum sensitivity	2 m V/V(AC) or 5 m V/V(DC)



NOTE—25.4 mm = 1 in.

FIGURE 1 Triaxial Chamber With External LVDT's and Internal Load Cell

6.3.4 Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The signal shall be clean and free of noise (use shielded cables for connections). If a filter is used, it should have a frequency which cannot attenuate the signal. The LVDT's should be wired separately so each LVDT signal can be monitored independently.

NOTE 2—In order to minimize errors in testing specimens, LVDT's should be calibrated daily and load cells should be calibrated once a week using a suitable proving ring. The load cell should be calibrated semiannually by an external agency. The entire system (transducer, conditioning, and recording devices) should be calibrated using synthetic samples of known modulus. Periodic checks of the system should be performed using reference samples.

6.4 *Specimen Preparation Equipment*—A variety of equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different materials and different methods of compaction in the field requires the use of varying compaction techniques in the laboratory. See Annex A and Annex B of this procedure for specimen compaction equipment.

6.5 Equipment for trimming test specimens from undisturbed thin-walled tube samples of subgrade soils shall be as described in T 296.

6.6 *Miscellaneous Apparatus*—This includes calipers, micrometer gauge, steel rule (calibrated to 0.05 mm (0.02 in.)), rubber membranes from 0.2 to 0.8 mm (0.01 to 0.031 in.) thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans and data sheets, as required.

7. PREPARATION OF TEST SPECIMENS

7.1 *Specimen Size*—Specimen length should not be less than two times the diameter. Minimum specimen diameter is 71-mm (2.8 in.) or five times the nominal particle size. (Nominal particle size is the sieve opening for which 95 percent of the material passes during the sieve analysis.) The following guidelines, based on sieve analysis test results shall be used to determine the test specimen size:

7.1.1 Use the 71-mm (2.8-in.) diameter undisturbed specimen from the thin-walled tube samples for cohesive subgrade soils (Material Type 2). The specimen length shall be at least two times the diameter [142 mm (5.6 in.)] and the specimen shall be prepared as described in Section 7.2. If undisturbed subgrade samples are unavailable or unsuitable for testing, then 71-mm (2.8-in.) diameter molds shall be used to reconstitute Type 2 test specimens.

7.1.2 Use 102-mm (4.0-in.) diameter split molds to reconstitute 203 mm (8-in.) high test specimens for all Type 1 soils when the nominal particle size does not exceed 19.0 mm ($^3/_4$ in.).

7.1.3 Use 152-mm (6.0 in.) diameter split molds to prepare 305-mm (12 in.) high test specimens for all Type 1 materials with nominal particle sizes between 19.0 and 31.5 mm ($^3/_4$ and $1^1/_4$ in.), without removing any coarse aggregate.

7.1.4 If more than 5 percent of a sample is retained on the 31.5-mm ($1^1/_4$-in.) sieve, remove the particles retained on the 31.5-mm sieve prior to specimen preparation. If more than 10 percent of the sample is plus 31.5-mm material, the specimen shall not be tested.

7.2 *Undisturbed Specimens*—Undisturbed subgrade soil specimens are trimmed and prepared as described in T 296, using the thin-walled tube samples of the subgrade soil. Determine the natural moisture content (w) of the tube sample following the procedure outlined in

T 265 and record in the test report. Determine the in situ density of the subgrade soil as specified in T 233.

The following procedure shall be followed for the thin-walled tube samples:

7.2.1 To be suitable for testing, a specimen of sufficient length (generally twice the diameter of the specimen after preparation) must be cut from the tube sample, and must be free from defects that would result in unacceptable or biased test results. Such defects include cracks in the specimen, edges sheared off that cannot be repaired during preparation, presence of particles much larger than that typical for the material (example, 25.0-mm (1-in.) gravel in a fine-grained soil), presence of "foreign objects" such as large roots, wood particles, organic material and gouges due to gravel hanging on the edge of the tube.

7.2.2 If a good undisturbed subgrade sample is unavailable from a particular location, a reconstituted specimen shall be prepared as described in Sections 7.3, 7.4, and 7.5. Select a sample for reconstitution. Determine the in situ moisture content (w) of material that is representative of the sample to be reconstituted (about 200 grams of the sample for moisture content determination) following the procedure outlined in T 265, and record on the test report. Assume the in-place density measured in the field as the basis for reconstitution. In the absence of the in situ moisture content and if in-place densities are not known, select the optimum moisture content and 95 percent of the maximum dry density (determined for the same layer using T 99 for reconstitution of the test specimen).

7.2.2.1 The moisture content of the laboratory compacted specimen should not vary more than ± 0.5 percentage point from the in situ moisture content obtained for that layer. The dry density of the laboratory compacted specimens should not vary by more than ± 5 percent of the in-place dry density for that layer.

7.2.2.2 Where thin-walled tube samples were not retrieved or are unsuitable for testing, then a representative test sample from the bulk samples of subgrade shall be used to prepare reconstituted specimens according to Sections 7.3, 7.4, and 7.5.

7.3 *Laboratory Compacted Specimens*—Reconstituted test specimens shall be prepared to approximate the in situ dry density (Y_d) and moisture content (w). These laboratory compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils for which undisturbed tube specimens could not be obtained.

7.3.1 If the sample is damp, dry it until it becomes friable. Drying may be in air or by use of a drying apparatus such that the temperature does not exceed 60°C (140°F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

7.3.2 Determine the moisture content (w_1) of the air-dried sample. The sample for moisture content shall have a mass of not less than 200 g for samples with a maximum particle size smaller than the 4.75-mm (No. 4) sieve and not less than 500 g for samples with a maximum particle size greater than the 4.75-mm (No. 4) sieve.

7.3.3 Determine the total volume (V) of the compacted specimen to be prepared. The height of the compacted specimen must be slightly greater than that required for resilient testing to allow for trimming of the specimen ends. An excess of 13 mm (0.5-in.) is generally adequate for this purpose.

7.3.4 Determine the mass of oven-dry soil solids (W_s) and water (W_w) required to obtain the desired dry density (Y_d) and moisture content (w) as follows:

$$W_s \text{ (kilograms)} = Y_d \text{ (kilograms per cubic meter)} \times V \text{ (cubic meters)}$$

$$W_w \text{ (kilograms)} = W_s \text{ (kilograms)} \times w \text{ (percent/100) OR}$$

$$W_s \text{ (pounds)} = Y_d \text{ (pounds per cubic foot)} \times V \text{ (cubic feet)}$$

$$W_w \text{ (pounds)} = W_s \text{ (pounds)} \times w \text{ (percent/100)}$$

7.3.5 Determine the total mass of the prepared material sample (W_t) required to obtain W_s to produce the desired specimen of volume V at dry density Y_d and moisture content w.

$$W_t \text{ (grams)} = W_s \times (1 + w/100)$$

7.3.6 Determine the mass of the dried sample (W_{ad}), with the moisture content (w_1), required to obtain W_s, including an additional amount W_{as} of at least 200 grams to provide material for the determination of moisture content at the time of compaction.

$$W_{ad} \text{ (grams)} = (W_s + W_{as}) \times (1 + W_1/100)$$

7.3.7 Determine the mass of water (W_{aw}) required to increase the mass from the existing dried mass of water (W_1) to the mass of water (W_w) corresponding to the desired compaction moisture content (w).

$$W_1 \text{ (grams)} = (W_s + W_{as}) \times (w_1/100)$$

$$W_2 \text{ (grams)} = (W_s + W_{as}) \times (w/100)$$

$$W_{aw} \text{ (grams)} = W_2 - W_1$$

7.3.8 Place the mass of the sample (W_{ad}) determined in Section 7.3.7 into a mixing pan.

7.3.9 Add the water (W_{aw}) to the sample in small amounts and mix thoroughly after each addition.

7.3.10 Place the mixture in a plastic bag. Seal the bag and place it in a second bag and seal it.

7.3.11 After mixing and storage, determine the mass of the wet soil and container to the nearest gram and record this value on the appropriate data sheet.

7.4 *Compaction Methods and Equipment for Reconstituting Specimens:*

7.4.1 *Compacting Specimens for Type 1 Materials*—The general method of compaction for these soils will be those of Annex A of this procedure.

7.4.2 *Compacting Specimens for Type 2 Materials*—The general method of compaction for Type 2 materials will be that of Annex B of this procedure.

7.4.3 *Moisture and Density for Compaction*—When the in situ density and moisture content are known from the field data (see Section 7.2.2) the sample should be compacted to this in situ dry density and moisture content.

7.4.4 *Moisture and Density for Compaction when Field Data is not Available*—in the absence of the field data and the in situ density and moisture contents are not known, one of the following procedures is used.

7.4.4.1 *Unbound Granular Base and Subbase Materials (Type 1)*—Use the results of T 180 to establish the maximum dry density and the optimum moisture

content. *Select* the optimum moisture content and 95 percent of the maximum dry density for sample compaction.

7.4.4.2 *Subgrade Soils (Type 1)*—Subgrade soils may be categorized as Type 1 or as Type 2 according to the criteria of Section 5. In the case of Type 1 subgrade soils, use the results of T 99 to establish the maximum dry density and the optimum moisture content. *Select* the optimum moisture content and 95 percent of the maximum dry density for sample compaction.

7.4.4.3 *Unbound Material Type 2*—Generally subgrade soils (fine-grained) are included in the unbound material Type 2 category. *Select* the optimum moisture content and 95-percent maximum dry density for sample compaction as described in Section 7.4.4.2.

7.4.4.4 The sample dry density and moisture content should not differ by more than 3 percent of the in situ dry density and 1 percentage point of the in situ moisture content respectively for Type 1 materials, and 2 percent of the in situ dry density and 0.5 percent of the in situ moisture content for Type 2 materials, respectively (See Note 3). If the remolded sample does not meet this criteria, it should be discarded.

NOTE 3—Example: if the desired dry density is 1922 kg/m^3 (120 lbs/ft^3) and desired moisture content is 8.0 percent for a Type 1 soil, a dry density between 1864 and 1980 kg/m^3 (116.4 and 123.6 lbs/ft^3) and a moisture content between 7.0 and 9.0 percent would be acceptable.

7.4.5 The specimen should be protected from moisture change and tested the same day it is compacted.

7.5 *Specific Gravity*—Determine the specific gravity of solids following T 100.

8. TEST PROCEDURE

8.1 *Resilient Modulus Test for Type 2 Soils*—The procedure described in this section is used for undisturbed or laboratory compacted specimens of Type 2 soils as defined in Section 5. Compacted specimens should be tested on the same day after preparation.

8.1.1 *Assembly of Triaxial Chamber*—Specimens trimmed from undisturbed samples and laboratory compacted specimens are placed in the triaxial chamber and loading apparatus in the following steps.

8.1.1.1 Place the triaxial chamber base assembly on a table close to the loading frame. If the chamber has a removable bottom platen (sample base) tighten it firmly to obtain an air tight seal.

8.1.1.2 Place a porous stone on the top of the pedestal or bottom end plate of the triaxial chamber.

8.1.1.3 Carefully place the specimen on the porous stone. Place the membrane on a membrane expander, apply vacuum to the membrane expander, then carefully place the membrane on the sample and remove the vacuum and the membrane expander. Seal the membrane to the pedestal (or bottom plate) with an O-ring or other pressure seals.

8.1.1.4 Place the top platen (with load cell included) on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some other pressure seal.

8.1.1.5 If the specimen has been compacted inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, steps in Sections 8.1.1.2, 8.1.1.3, and 8.1.1.4 are omitted. Instead, the "specimen assembly" is placed on the top of the pedestal or bottom end plate of the triaxial chamber.

8.1.1.6 Connect the specimen's bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 7 kPa (1 psi). If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap and base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

8.1.1.7 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, the load cell on the porous stone, and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.

8.1.1.8 Slide the assembly apparatus into position under the axial loading device. Bring the loading device down and couple it to the triaxial chamber piston and apply a seating pressure to the sample of 14 kPa (2 psi) in order to obtain full contact of the piston with the top platen.

8.1.2 *Conduct the Resilient Modulus Test*—The following steps are required to conduct the resilient modulus test on a specimen of Type 2 soil which has been installed in the triaxial chamber and placed under the loading frame.

8.1.2.1 Open all drainage valves leading into the specimen.

8.1.2.2 If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply a confining pressure of 41 kPa (6 psi) to the test specimen. A minimum contact load of 10 percent ($.1S_d$) of the maximum applied load shall be maintained during all repeated load applications.

8.1.2.3 *Conditioning*—Begin the test by applying 1000 repetitions of a deviator stress of 28 kPa (4 psi) using a haversine shaped load pulse consisting of a 0.1-second load followed by a 0.9-second rest period. The foregoing stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the end platens and the test specimen.

8.1.2.4 *Testing Specimen*—The testing is performed following the loading sequence shown in Table 1. Begin by decreasing the deviator stress to 14 kPa (2 psi) (Sequence No. 1, Table 1). Apply 100 repetitions of deviator stress using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9-second rest period and record the average of the recovered deformations of the last five cycles on an appropriate data sheet.

8.1.2.5 Increase the deviator stress to 28 kPa (4 psi) (Sequence No. 2) and repeat step 8.1.2.4 at this new stress level.

8.1.2.6 Increase the deviator stress to 41 kPa (6 psi) (Sequence No. 3) and repeat step 8.1.2.4 at this new stress level.

8.1.2.7 Continue the test for the remaining load sequences in Table 1 (4 to 15) recording the vertical recovered deformation. If at any time the permanent

TABLE 1 Testing Sequence for Type 2 Soils

Sequence No.	Confining Pressure S_3 kPa	Deviator Stress S_d kPa	Number of Load Applications
0*	41	28	1000
1	41	14	100
2	41	28	100
3	41	41	100
4	41	55	100
5	41	69	100
6	21	14	100
7	21	28	100
8	21	41	100
9	21	55	100
10	21	69	100
11	0	14	100
12	0	28	100
13	0	41	100
14	0	55	100
15	0	69	100

*(preconditioning).
6.9 kPa = 1 psi.

strain of the sample exceeds 10 percent, stop the test and report the result on an appropriate data sheet.

8.1.2.8 At the completion of the loading sequences, disassemble the triaxial cell.

8.1.2.9 Measure the length of the specimen after the test.

8.1.2.10 Correct the specimen gage length for permanent deformation. A simple correction is done by taking an average of the specimen length measurement before and after the test.

8.1.2.11 Remove the membrane from the specimen and use the entire specimen to determine moisture content. Record this value on the appropriate data sheet.

8.2 *Resilient Modulus Test for Type 1 Materials*—The procedure described in this section applies to all unbound granular base and subbase materials and all unbound subgrade soils which contain less than 70 percent passing the 2.00-mm (10 sieve) and a maximum of 20 percent passing the 0.075-mm (No. 200) sieve.

8.2.1 *Assembly of the Triaxial Chamber*—Follow steps in Sections 8.1.1.1 through 8.1.1.8. When compaction is completed, place the porous stone and top sample cap on the surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane should be sealed tightly against the cap with the O-ring seal. If it does not, the seal can be applied later.

8.2.1.1 Place the triaxial chamber base assembly on a table close to the loading frame. If the chamber has a removable bottom platen (sample base) tighten it firmly to obtain an air tight seal.

8.2.1.2 Place a porous stone on the top of the pedestal or bottom end plate of the triaxial chamber.

8.2.1.3 Carefully place the specimen on the porous stone. Place the membrane on a membrane expander, apply vacuum to the membrane expander, then carefully place the membrane on the sample and remove the vacuum and the membrane expander. Seal the membrane to the pedestal (or bottom plate) with an O-ring or other pressure seals.

8.2.1.4 Place the top platen (with load cell included) on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some other pressure seal.

8.2.1.5 If the specimen has been compacted inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, steps in Sections 8.2.1.2, 8.2.1.3, and 8.2.1.4 are omitted. Instead, the "specimen assembly" is placed on the top of the pedestal or bottom end plate of the triaxial chamber.

8.2.1.6 Connect the specimen's bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 7 kPa (1 psi). If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap and base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

8.2.1.7 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, the load cell on the porous stone, and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.

8.2.1.8 Slide the assembly apparatus into position under the axial loading device. Bring the loading device down and couple it to the triaxial chamber piston and apply a seating pressure to the sample of 14 kPa (2 psi) in order to obtain full contact of the piston with the top platen.

8.2.1.9 Connect the chamber pressure supply line and apply a confining pressure of 103 kPa (15 psi).

8.2.1.10 Remove the vacuum supply from the vacuum saturation inlet and close this line.

8.2.2 *Conduct the Resilient Modulus Test*—After the test specimen has been prepared and placed in the loading device, the following steps are necessary to conduct the resilient modulus testing:

8.2.2.1 If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell. This can be done by applying a seating pressure of 14 kPa (2 psi). A minimum contact load of 10 percent ($.1S_d$) of the maximum applied load shall be maintained during all repeated load determinations.

8.2.2.2 Adjust the recording devices for the LVDT's and load cell as needed.

8.2.2.3 Set the confining pressure to 103 kPa (15 psi) and apply 1000 repetitions of an axial deviator stress of 103 kPa (15 psi) using a haversine shaped load pulse consisting of a 0.1-second

TABLE 2 Testing Sequence for Type 1 Soils

Sequence No.	Confining Pressure S_3 kPa	Deviator Stress S_d kPa	Number of Load Applications
0*	103	103	1000
1	21	21	100
2	21	41	100
3	21	62	100
4	34	34	100
5	34	69	100
6	34	103	100
7	69	69	100
8	69	138	100
9	69	207	100
10	103	69	100
11	103	103	100
12	103	207	100
13	138	103	100
14	138	138	100
15	138	276	100

*(preconditioning).
6.9 kPa = 1 psi.

load followed by a 0.9-second rest period. The drainage valve should be open throughout the resilient testing. This stress sequence constitutes the sample conditioning.

8.2.2.4 *Testing the Sample.* The testing is performed following the loading sequences in Table 2 using a haversine shaped load pulse consisting of a 0.1-second load followed by a 0.9-second rest period. Decrease the deviator stress to 21 kPa (3 psi) and set the confining pressure to 21 kPa (3 psi) (Sequence No. 1, Table 2). Apply 100 repetitions of deviator stress and record the average of the deformations of the last five load cycles on the appropriate data form.

8.2.2.5 Continue with Sequence No. 2 increasing the deviator stress to 41 kPa (6 psi) and repeat 8.2.2.4 at this new stress level.

8.2.2.6 Continue the test for the remaining load sequences in Table 2 (3 to 15) recording the vertical recovered deformation. If, at any time the total vertical permanent strain deformation exceeds 10 percent, stop the test and report the results on an appropriate data form.

8.2.2.7 At the completion of the load sequences in Table 2, reduce the confining pressure to zero and disassemble the triaxial cell.

8.2.2.8 Measure the length of the specimen after the test.

8.2.2.9 Correct specimen gage lengths for permanent deformation. A simple correction is done by taking an average of lengths measured before and after the test.

8.2.2.10 Remove the membrane from the specimen and use the entire sample to determine the moisture content. Record this value on an appropriate data sheet.

9. CALCULATIONS

9.1 Perform calculations using the tabular arrangement shown in Figure 2 through Figure 5.

9.1.1 Calculate the mean and standard deviation of the load and recoverable deformation. The mean values are used to calculate the deviator stress and the resilient strain.

10. REPORT

10.1 Report the following information:

10.1.1 Specimen identification information.

10.2 Test Results.

10.2.1 Record the test data for each specimen of Type 1 material on forms similar to Figures 2 and 3. Record the test data for each specimen of Type 2 material on forms similar to Figures 4 and 5.

10.2.2 *M Relationships and Plots:* Plot Log M_r versus Log S_b (Type 1) or Log M_r versus Log S_d (Type 2). Attach the appropriate plots. Determine the appropriate coefficients (k_3 and k_4 for Type 1 and k_1 and k_2 for Type 2) using least squares regression. Example plots are shown in Figure 6 (Type 1) and Figure 7 (Type 2).

Simple relationship for Type 1 Material (Figure 6):

$$M_r = k_3(S_b)^{k_4} \text{ Where } S_b = \text{bulk stress} = S_d + 3S_3$$

Simple relationship for Type 2 Material (Figure 7):

$$M_r = k_1(S_d)^{k_2} \text{ Where } S_d = \text{deviator stress}$$

Report the regression equation and the coefficient of determination on the data plot.

10.3 Comments should be included with the test results.

11. PRECISION AND BIAS

11.1 At the present time, there is insufficient data available to justify providing a precision and bias statement for this test method.

12. KEYWORDS

12.1 Resilient modulus, pavement design, materials testing, laboratory equipment, unbound granular base, subbase, and subgrade.

ANNEX I

COMPACTION OF TYPE 1 SOILS

A1. SCOPE

A1.1 This method covers the compaction of Type 1 soils for use in resilient modulus testing.

A1.2 Type 1 soils will be recompacted using 102-mm and 152-mm (4.0 and 6.0-in.) split molds and vibratory compaction. Split molds 102-mm (4.0-in.) in diameter shall be used to reconstitute 203-mm (8-in.) high test samples for all Type 1 material with a nominal

1. SAMPLE IDENTIFICATION: ______________________________

____

2. SPECIMEN INFORMATION:

SPECIFIC GRAVITY	___ . ___ ___ ___
SPECIMEN DIAMETER, mm	
TOP	___ ___ ___ . ___
MIDDLE	___ ___ ___ . ___
BOTTOM	___ ___ ___ . ___
AVERAGE	___ ___ ___ . ___
MEMBRANE THICKNESS, mm	___ . ___
NET DIAMETER, mm	___ ___ ___ . ___
HEIGHT OF SPEC. + CAP + BASE mm	___ ___ ___ . ___
HEIGHT OF CAP + BASE, mm	___ ___ ___ . ___
INITIAL LENGTH, L_0, mm	___ ___ ___ . ___
AFTER TEST LENGTH, L_1, mm	___ ___ ___ . ___
INSIDE DIAMETER OF MOLD, mm	___ ___ ___ . ___

3. SOIL SPECIMEN MASS:

INITIAL MASS OF CONTAINER AND WET SOIL, g	* ___ ___ ___ ___ ___ . ___ ___
FINAL MASS OF CONTAINER AND WET SOIL, g	* ___ ___ ___ ___ ___ . ___ ___
MASS OF WET SOIL USED, g	* ___ ___ ___ ___ ___ . ___ ___

4. SOIL SPECIMEN VOLUME:

INITIAL AREA, A_0 mm^2	___ ___ ___ ___ .
INITIAL VOLUME, $A_0 * L_0$, mm^3	___ ___ ___ ___ ___ ___ ___ .

5. SOIL PROPERTIES:

WET DENSITY, kg/m^3	___ ___ ___ ___ .
COMPACTION MOISTURE CONTENT	** ___ ___ . ___
SATURATION, S, PERCENT	___ ___ . ___
DRY DENSITY, γ_d, kg/m^3	___ ___ ___ ___ .
MOISTURE CONTENT AFTER M_r TESTING, PERCENT	___ ___ . ___

6. COMMENTS ______________________________

____

____

FIGURE 2 Example Data Sheet for Recording Specimen Information for Type 1 Soils

particle size which does not exceed 19.0 mm ($^3/_4$ in.). Split molds 152-mm (6.0-in.) in diameter shall be used to prepare 305-mm (12-in.) high test samples for all Type 1 materials with nominal particle sizes between 19.0 and 31.5 mm ($^3/_4$ and $1^1/_4$ in.). Cohesionless soils are compacted readily by use of a split mold mounted on the base of the triaxial cell as shown in Figure A1. Compaction forces are generated by a small hand-held air hammer.

A2. APPARATUS

A2.1 102-mm (4.0-in.) diameter split mold.

A2.2 152-mm (6.0-in.) diameter split mold.

A2.3 Vibratory compaction device.

A3. PROCEDURE

A3.1 Tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained.

A3.2 Place the two porous stones and the top platen on the bottom platen. Determine the total height of the top and bottom platens and stones to the nearest 0.25 mm (0.01 in.).

A3.3 Remove the top platen and upper porous stone if used. Measure the thickness of the rubber membrane with a micrometer.

A3.4 Place the rubber membrane over the bottom platen and lower porous

SAMPLE IDENTIFICATION:______________________________

RESILIENT MODULUS TESTING.

A Chamber Confining Pressure S_3 (kPa)	B Nominal Deviator Stress S_d (kPa)	C Mean Deviator Load kg*	D Standard Deviation of Load (kg)*	E Mean Applied Dev. Stress (kPa)*	F Mean Recov. Def. LVDT #1 Reading (mm)*	G Mean Recov. Def. LVDT #2 Reading (mm)*	H Mean Recoverable Deformation (mm)*	I Std. Dev. of Recoverable Deformation (mm)*	J Mean of Resilient Strain (mm/mm)*	K Mean of M_r (kPa)*	L Standard Dev. of M_r (kPa)	M Bulk Stress S_b (kPa)*
21	21											
21	41											
21	62											
34	34											
34	69											
34	103											
69	69											
69	138											
69	207											
103	69											
103	103											
103	207											
138	103											
138	138											
138	276											

* obtained from the last five load cycles

FIGURE 3 Example Data Sheet for Resilient Modulus of Type 1 Soils

stone. Secure the membrane to the bottom platen using an O-ring or other means to obtain an airtight seal.

A3.5 Place the split mold around the bottom platen and draw the membrane up through the mold. Tighten the split mold firmly in place. Exercise care to avoid pinching the membrane.

A3.6 Stretch the membrane tightly over the rim of the mold. Apply a vacuum to the mold to draw the membrane in contact. If wrinkles are present in the membrane, release the vacuum, adjust the membrane and reapply the vacuum. The use of a porous plastic forming jacket line helps to ensure that the membrane fits smoothly inside the mold. The vacuum is maintained throughout the compaction procedure.

A3.7 Measure, to the nearest 0.25 mm (0.01 in.), the inside diameter of the membrane lined mold and the distance between the top of the lower porous stone and the top of the mold.

A3.8 Determine the volume, V, of the specimen to be prepared using the diameter determined in step A3.7 and a value of height between 142 mm (5.6 in.) and the height measured in step A3.7.

A3.9 Determine the mass of material, at the desired water content, to be compacted into the volume, V, to obtain the desired density.

A3.10 Establish the number of layers, N, to be used to compact the soil. For this procedure, N should be an odd number and shall have a minimum value of 3. The thickness of individual layers shall be limited to 305 mm (12 in.). Determine the mass of wet soil, W_L required for each layer.

$$W_L = W_t/N$$

where:

W_t = total mass of test specimen to produce appropriate density,
N = number of layers to be compacted.

A3.11 Place the total required mass of soil, W_{ad} into a mixing pan. Add the required amount of water, W_{aw} and mix thoroughly.

A3.12 Determine the mass of wet soil and the mixing pan.

A3.13 Place the amount of wet soil, W_L, into the mold. Avoid spillage. Using a spatula, draw soil away from the inside edge of the mold to form a small mound at the center.

A3.14 Insert the vibrator head and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in step A3.7 minus the thickness of the layer selected in step A3.10. This may require removal and reinsertion of the vibrator several times until experience is gained in gaging the vibration time which is required.

A3.15 Repeat steps A3.13 and A3.14 for each new layer. The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the layer thickness selected in step A3.10. The final surface shall be a smooth horizontal plane.

A3.16 When the compaction process is completed, determine the mass of the

1. SAMPLE IDENTIFICATION: ______________________

____

2. SPECIMEN INFORMATION:
SPECIFIC GRAVITY ___ . ___ ___ ___
SPECIMEN DIAMETER, mm
TOP ___ ___ ___ . ___
MIDDLE ___ ___ ___ . ___
BOTTOM ___ ___ ___ . ___
AVERAGE ___ ___ ___ . ___
MEMBRANE THICKNESS, mm ___ . ___
NET DIAMETER, mm ___ ___ ___ . ___
HEIGHT OF SPEC. + CAP + BASE mm ___ ___ ___ . ___
HEIGHT OF CAP + BASE, mm ___ ___ ___ . ___
INITIAL LENGTH, L_0, mm ___ ___ ___ . ___
AFTER TEST LENGTH, L_f, mm ___ ___ ___ . ___
INSIDE DIAMETER OF MOLD, mm ___ ___ ___ . ___

3. SOIL SPECIMEN MASS:
INITIAL MASS OF CONTAINER AND WET SOIL, g * ___ ___ ___ ___ ___ . ___ ___
FINAL MASS OF CONTAINER AND WET SOIL, g * ___ ___ ___ ___ ___ . ___ ___
MASS OF WET SOIL USED, g * ___ ___ ___ ___ ___ . ___ ___

4. SOIL SPECIMEN VOLUME:
INITIAL AREA, A_0 mm^2 ___ ___ ___ ___ .
INITIAL VOLUME, $A_0 * L_0$, mm^3 ___ ___ ___ ___ ___ ___ ___ .

5. SOIL PROPERTIES:
WET DENSITY, kg/m^3 ___ ___ ___ ___ .
COMPACTION MOISTURE CONTENT ** ___ ___ . ___
SATURATION, S_r PERCENT ___ ___ . ___
DRY DENSITY, Y_d, kg/m^3 ___ ___ ___ ___ .
MOISTURE CONTENT AFTER M_r TESTING, PERCENT ___ ___ . ___

6. COMMENTS ______________________

____

____

Notes: * If a thin-walled tube is used for resilient modulus testing, these items do not need to be reported.

** If a thin-walled tube is used for resilient modulus testing, record the moisture content of the pavement layer being tested.

FIGURE 4 Example Data Sheet for Recording Specimen Information for Type 2 Soils

mixing pan and the excess soil. This mass subtracted from the mass determined in step A3.12 is the mass of the wet soil used (mass of specimen). Verify the compaction water, W_c of the excess soil. The moisture content of this sample shall be conducted using AASHTO T 265-86. Proceed with Section 8.2 of this procedure.

ANNEX II

COMPACTION OF TYPE 2 SOILS

B1. SCOPE

B1.1 This method covers the compaction of Type 2 soils for use in resilient modulus testing.

B1.2 The general method of compaction of Type 2 soils will be that of static loading (also known as the double plunger method). If testable thin-walled tubes are available, specimens shall not be recompacted.

B1.3 Specimens shall be recom-

SAMPLE IDENTIFICATION:____

RESILIENT MODULUS TESTING.

A Chamber Confining Pressure S_3 (kPa)	B Nominal Deviator Stress S_d (kPa)	C Mean Deviator Load kg*	D Standard Deviation of Load (kg)*	E Mean Applied Dev. Stress (kPa)*	F Mean Recov. Def. LVDT #1 Reading (mm)*	G Mean Recov. Def. LVDT #2 Reading (mm)*	H Mean Recoverable Deformation (mm)*	I Std. Dev. of Recoverable Deformation (mm)*	J Mean of Resilient Strain (mm/mm)*	K Mean of M_r (kPa)*	L Standard Dev. of M_r (kPa)
41	14										
41	28										
41	41										
41	55										
41	69										
21	14										
21	28										
21	41										
21	55										
21	69										
0	14										
0	28										
0	41										
0	55										
0	69										

* obtained from the last five load cycles

FIGURE 5 Example Data Sheet for Resilient Modulus of Type 2 Soils

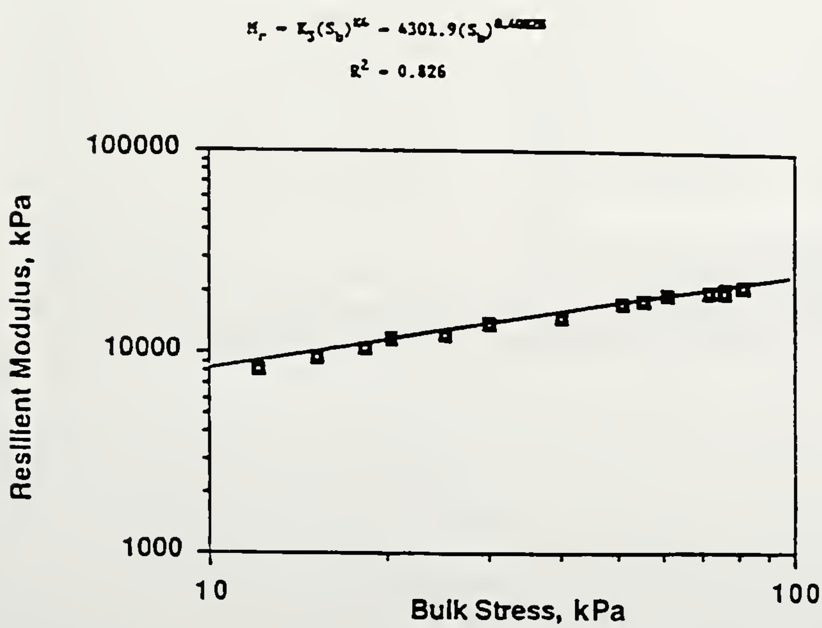


FIGURE 6 Example Logarithmic Plot of Resilient Modulus (M_r) vs. Bulk Stress (S_b) for Type 1 Materials

pacted in a 71-mm (2.8-in.) diameter mold. The process is one of compacting a known mass of soil to a volume that is fixed by the dimensions of the mold assembly (mold shall be of a sufficient size to produce specimens 71 mm (2.8 in.) in diameter and 142 mm (5.6 in.) in height). A typical mold assembly is shown in Figure B1. Several steps are required for static compaction.

B2. APPARATUS

B2.1 As shown in Figure B1.

B3. PROCEDURE

B3.1 Five layers of equal mass shall be used to compact the specimens using this procedure. Determine the mass of wet soil, W_L to be used per layer where $W_L = W_t/5$.

B3.2 Place one of the loading rams into the specimen mold.

B3.3 Place the mass of soil, W_L determined in Step B3.1 into the specimen

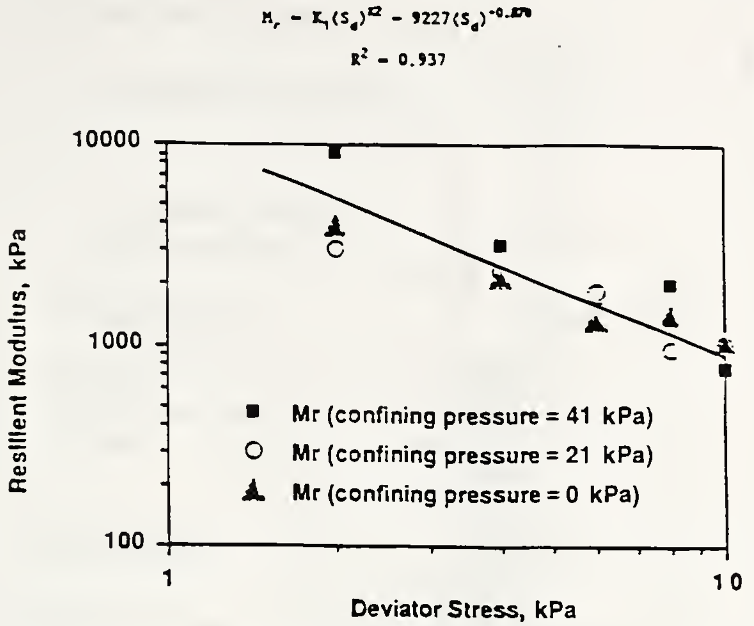


FIGURE 7 Example Logarithmic Plot of Resilient Modulus (M_r) vs. Deviator Stress (S_d) for Type 2 Materials

mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

B3.4 Insert the second ram and place the assembly in the static loading machine. Apply a small load. Adjust the position of the mold with respect to the soil mass, so that the distances from the mold ends to the respective load ram caps are equal. Soil pressure developed by the initial loading will serve to hold the mold in place. By having both loading rams reach the zero volume change simultaneously, more uniform layer densities are obtained.

B3.5 Slowly increase the load until the loading caps rest firmly against the mold. Maintain this load for a period of not less than 60 seconds. The amount of soil rebound depends on the rate of loading and load duration. The slower the rate of loading and the longer the load is maintained, the less the rebound. To obtain uniform densities, extreme care must be taken to center the first soil layer exactly between the ends of the specimen mold. Checks and any necessary adjustments should be made after completion of steps B4 and B5.

B3.6 Decrease the load to zero and remove the assembly from the loading machine.

B3.7 Remove the loading ram. Scarify the surfaces of the compacted layer and put the mass of wet soil W_L for the second layer in place and form a mound. Add a spacer ring and insert the loading ram.

B3.8 Invert the assembly and repeat step B3.7.

B3.9 Place the assembly in the loading machine. Increase the load slowly until the spacer rings firmly contact the ends of the specimen mold. Maintain this load for a period of not less than 60 seconds.

B3.10 Repeat steps B3.7, B3.8, and B3.9 to compact the remaining two layers.

B3.11 After compaction is completed, determine the moisture content of the remaining soil using T 265.

B3.12 Using the extrusion ram, press the compacted soil out of the specimen mold and into the extrusion mold. Extrusion should be done slowly to avoid impact loading the specimen.

B3.13 Using the extrusion mold, carefully slide the specimen off the ram, onto a solid end platen. The platen should be circular with a diameter equal to that of the specimen and have a minimum thickness of 13 mm (0.5 in.). Platens shall be of a material which will not absorb soil moisture.

B3.14 Determine the mass of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.25 mm (0.01 in.).

B3.15 Place a platen similar to the one used in step B3.13 on top of the specimen.

B3.16 Using a vacuum membrane expander, place the membrane over the specimen. Carefully pull the ends of the membrane over the end platens. Secure the membrane to each platen using O-rings or other means to provide an air-tight seal. Proceed with Section 8.1 of this procedure.

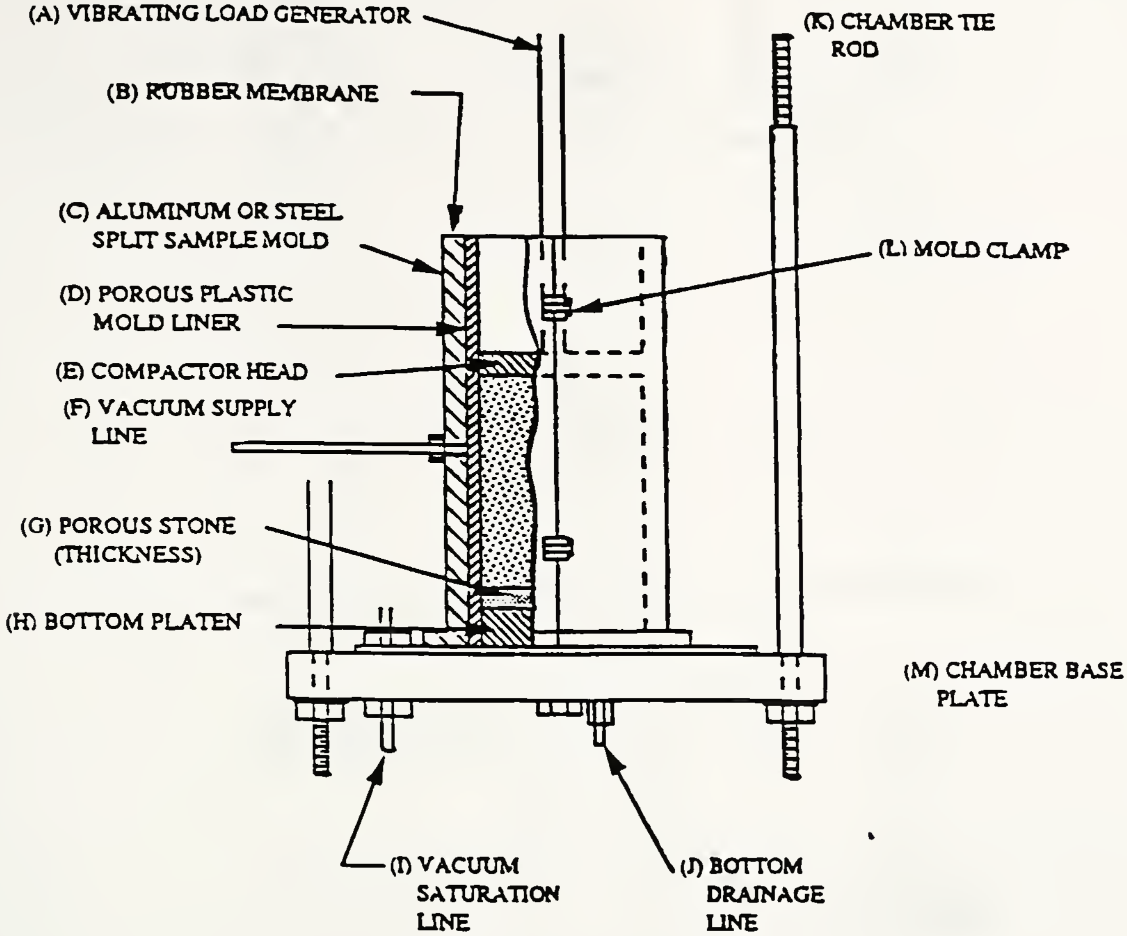


TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M
METRIC, mm	Note 1	Note 2	Note 2	Note 2	Note 3	6.4	6.4	38.1	6.4	6.4	12.7	Note 1	25.4
ENGLISH, in.						0.25	0.25	1.50	0.25	0.25	0.50		1.00

NOTE:
1. Dimension varies with manufacturer.
2. Dimension varies with specimen size.
3. Diameter should be 6.35 ± 0.50 mm (0.25 ± 0.02 in.) smaller than specimen diameter.

FIGURE A1 Apparatus for Vibratory Compaction of Type 1 Unbound Materials

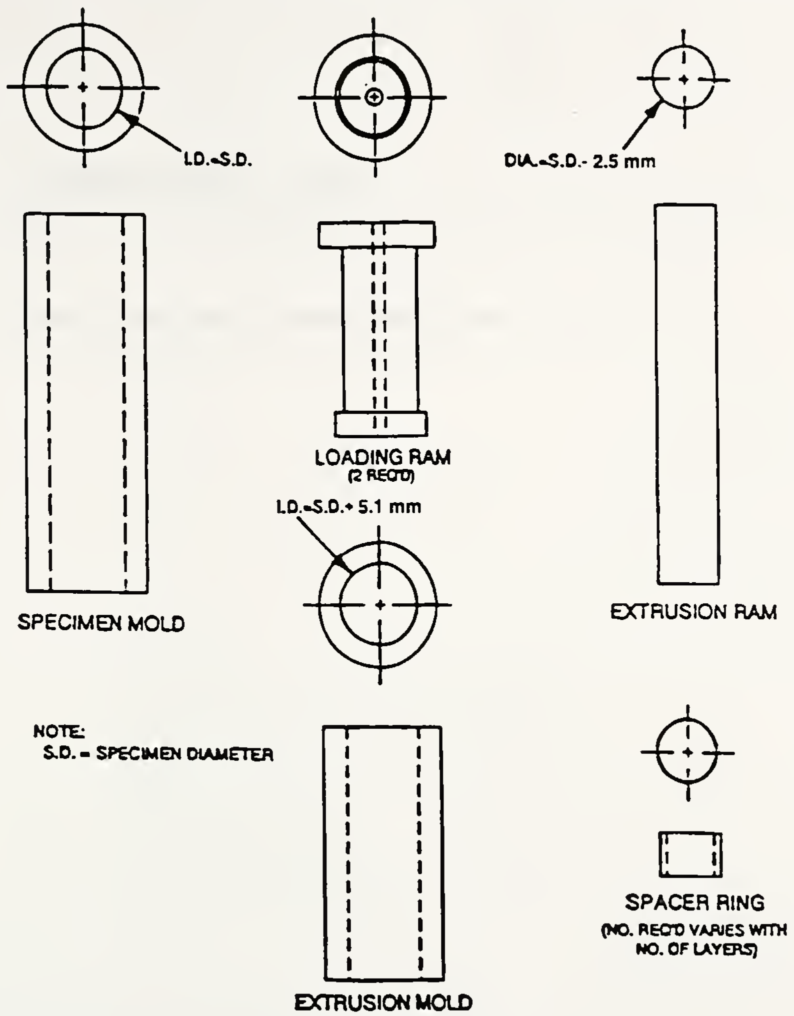


FIGURE B1 Apparatus for Static Compaction of Type 2 Unbound Materials

MTS®

User's Manual

Soil Resilient Modulus Test

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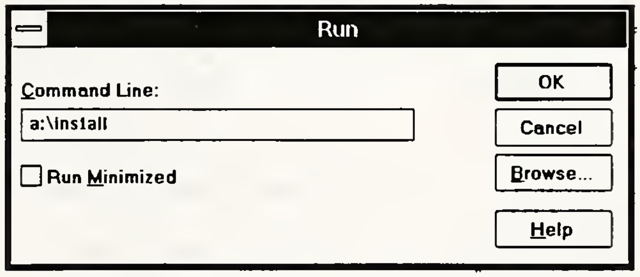
APR 1994
150313-02A

Soil Resilient Modulus Test

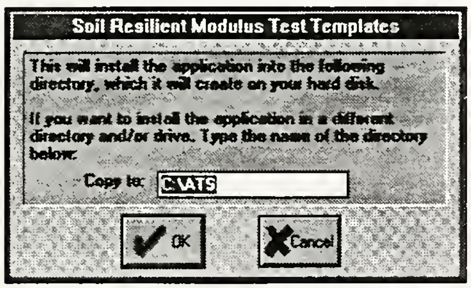
Installation

From the Windows Program Manager, open the File menu and choose the Run command. The Run dialog box opens. Type `a:\install` (or `b:\install` depending on which floppy disk drive you are using) as the command line.

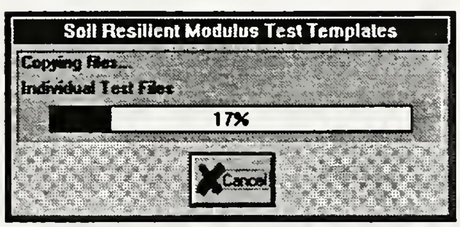


Click OK. The installation executable program starts.

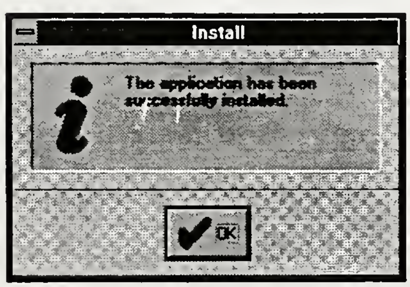
Next, enter the directory where the ATS software is installed. In most cases this is C:\ATS.



Click OK. The installation starts. Various screens are displayed during installation to indicate progress.



A final window indicates that installation was successful. Click OK to complete the installation.



Template Definitions

There are two separate templates defined for the Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils tests, one for Type 1 tests and one for Type 2 tests. These templates define and run resilient modulus tests per MTS' interpretation of AASHTO T 294-92 I.*

Some files in these two templates are shared. These are:

Specimen File	T294.SPC
Schedule File	T294.SCD

Type 1 Template

The Type 1 template contains the following test and sequence files:

Test Files	PRECOND.TST S3_0PSI.TST S3_3PSI.TST S3_5PSI.TST S3_10PSI.TST S3_15PSI.TST S3_20PSI.TST SD_3PSI.TST SD_5PSI.TST SD_6PSI.TST SD_9PSI.TST SD_10PSI.TST SD_15PSI.TST SD_20PSI.TST SD_30PSI.TST SD_40PSI.TST
Test Sequence File	TYPE1.SEQ

The T 294-92 I Type 1 test consists of 1000 cycles of preconditioning at 15 psi confining pressure (S3) and a calculated 15 psi deviator stress (SD), and then reducing the confining pressure to 3 psi and applying 100 load cycles at different levels of deviator stress. The confining pressure is then increased to 5 psi and a different series of 100 load cycles is applied. The same process is repeated at different deviator stresses for confining pressures of 10, 15, and 20 psi.

* All references to the AASHTO T 294-92 I standard assume MTS interpretation of that standard.

Type 2 Template

The Type 2 template contains the following test and sequence files:

Test Files	PRECOND.TST S3_0PSI.TST S3_3PSI.TST S3_6PSI.TST SD_2PSI.TST SD_4PSI.TST SD_6PSI.TST SD_8PSI.TST SD_10PSI.TST
Test Sequence File	TYPE2.SEQ

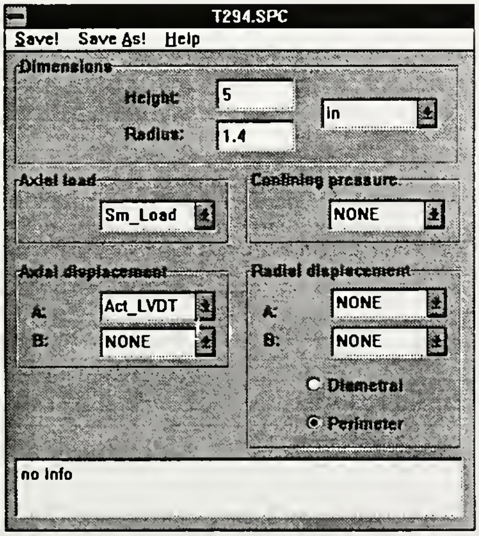
The T 294-92 I Type 2 test consists of 1000 cycles of preconditioning at 6 psi confining pressure (S3) and a calculated 4 psi deviator stress (SD), and then applying 100 load cycles at five levels of deviator stress (2, 4, 6, 8 and 10 psi). The confining pressure is then reduced to 3 psi and the same 100-cycle series is applied. Finally, the confining pressure is reduced to 0 psi and the 100-cycle series is applied again.

Editing the Specimen File

T294.SPC is the specimen file defined for both the Type 1 and Type 2 tests. It defines the specimen size, axial load channel, axial displacement channel(s), and confining pressure channel.

The first time you use this template for a Type 1 or Type 2 test, you can select all of the parameters in this file and save the selections so they will appear as defaults in the template. When using the template after the defaults have been selected and saved, you will typically need to edit only the specimen dimensions.

To edit the specimen file, open the T294.SPC file using the Specimen command from the ATS Editor Edit menu. The following window appears:



The following table describes the controls on this window. As shown in the right column, you will typically need to edit only the specimen dimensions.

Parameter	Definition	Action	Key*
Dimensions	The **Height**, **Radius** and units fields define your specimen.	Type your specimen's exact dimensions and select the appropriate units.	✗
Axial load	This pop-up menu selects the load transducer to be used for data acquisition.	Select the correct load transducer.	D
Axial displacement	These **A** and **B** pop-up menus select the external displacement transducers used for data acquisition.	Select the correct displacement transducers.	D
Confining pressure	This pop-up menu selects the confining pressure transducer.	Select the correct confining pressure transducer.	D
Radial displacement	The **A** and **B** pop-up menus and **Diametral/Perimeter** radio buttons select parameters for radial displacement transducers.	No editing necessary. No radial displacement is required for T 294-92 tests.	D

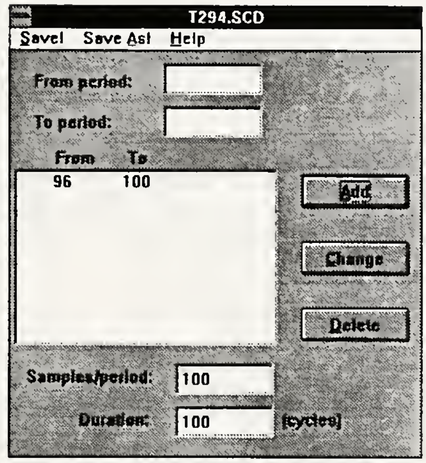
* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

Edit the Schedule File

T294.SCD is the schedule file for both the Type 1 and Type 2 tests. This file is used to set the test duration (number of cycles) and the periods over which data will be collected for the SD (100-cycle deviator stress) portions of the tests. (The cycle durations for the preconditioning and S3 portions of the test are defined on their respective Test File windows.)

You should not have to edit the schedule file unless you want to change the data collection rate (**Samples/period**), or the period over which data will be collected.

If it is necessary to edit the file, open T294.SCD using the Schedule command from the ATS Editor Edit menu. The following window appears:



When defining intervals, make sure to note that intervals cannot overlap or contain a period that is outside of the duration.

Parameter	Definition	Action	Key*
From period	The **From period** field defines the cycle at which collection starts for a data collection interval.	Type the desired cycle number. Refer to the **Add or Change** button description to enter the value into the **From/To** table.	D
To period	The **To period** field defines the cycle after which collection stops for the data collection interval.	Type the desired cycle number. Refer to the **Add** or **Change** button description to enter the value into the **From/To** table.	D
From/To	The **From/To** interval table lists the data collection intervals defined with the **From period** and **To period** fields.	The entries in this table are defined by the **Add**, **Change**, and **Delete** buttons described next. T 294-92 I tests require that data from the last five of 100 cycles be collected.	D
Add	The **Add** button is used to add data collection intervals to the **From/To** interval table.	Type cycle numbers in the **From period** and **To period** fields, and click **Add** to add the specified data collection interval to the table.	—

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Change	The **Change** button is used to change data collection intervals that are already in the **From/To** interval table.	Click on the interval you want to change in the table, edit the numbers in the **From period** and **To period** fields, and click **Change** to change the selected data collection interval.	—
Delete	The Delete button is used to delete data collection intervals from the **From/To** interval table.	Click on the interval you want to delete from the table and click **Delete** to delete the selected data collection interval.	—
Samples/period	The **Samples/period** field contains the number of data samples to be taken for each period (cycle) in the data collection interval(s).	Type the number of data samples per period (cycle).	D
Duration	The **Duration** field contains the number of cycles (load applications) that will be completed in a test that uses this schedule.	Type the number of cycles. For T 294-92 I tests, this number should be 100.	D

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

Edit the Test Files

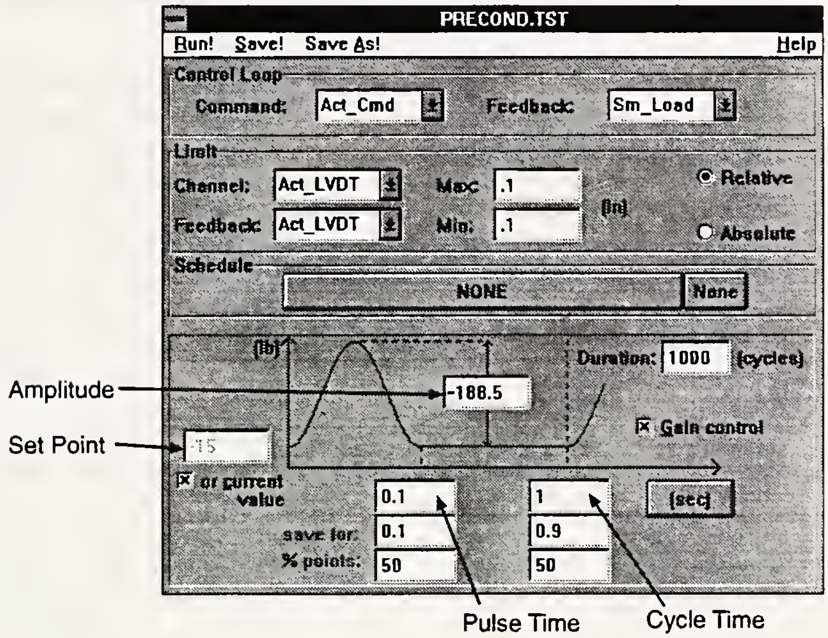
There are sixteen .TST files for Type 1 tests and nine .TST files for Type 2 tests. They are listed on pages 2 and 3 of this document. Each of these files falls into one of three categories:

- Preconditioning – These two files contain the preconditioning parameters for the test. They are both named PRECOND.TST. You probably *will* have to edit these files to enter the load (or force) amplitude that will achieve the desired deviator stress.
- S3 (Confining Pressure) Files – These files ramp the confining pressure from its current level up or down to a different level. They are named S3_*xx*PSI.TST, where the *xx* is the confining pressure that the .TST file ramps to. For example, S3_3PSI.TST ramps the pressure from its current level to 3 psi. You probably *will not* have to edit these files.
- SD (Deviator Stress) Files – These files apply 100 load cycles (as defined by the T294.SCD schedule file) at a calculated deviator stress. They are named SD_*xx*PSI.TST, where *xx* is the deviator stress. For example, SD_20PSI.TST applies 100 load cycles at 20 psi calculated deviator stress. You *will* have to edit these files to enter the load (or force) amplitude that will achieve the desired deviator stress.

To edit a test file, open the file using the ATS Test menu Edit command. One of three types of windows will appear. These three windows are described separately in the following sections.

Preconditioning Files

When you open a preconditioning test file, a window similar to the following appears:



As shown on the following table, you will have to edit the **Set Point** and **Amplitude** parameters on this window for each test. You may also want to check the validity of the **Limit** selections. The rest of the parameters can typically be defined as defaults and saved in the template.

Parameter	Definition	Action	Key*
Control Loop	The **Command** and **Feedback** pop-up menus select parameters for the control loop.	Select the desired command and feedback variables. For this type of test, you should select an axial command and a load feedback.	D
Limit	The **Channel** and **Feedback** pop-up menus and the **Max** and **Min** fields provide an interlock backup to stop the test in case of specimen failure. When a limit on the selected channel is exceeded, the system transfers control from the **Command** channel to the selected **Limit Feedback** channel. The **Relative** and **Absolute** radio buttons select whether the limit values will be actual values relative to the operating range (**Absolute**) or values relative to the starting value of the test(**Relative**).	Select the desired **Channel** and **Feedback** parameters. Type the appropriate limit values in the **Max** and **Min** fields (in the units shown). Select the **Relative** or **Absolute** limit value. The maximum and minimum limits should be a value that minimizes the chance of equipment damage. The actual value will depend on channel selection and specimen type.	✓

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Schedule	The long button opens a selection window to allow you to select a schedule file for this test. The **None** button selects no schedule for this test.	There is no data collection required for preconditioning. Click **None**. If you want to select a schedule file, click the long button and select the desired schedule file.	D
Set Point	The **Set Point** field sets the mean level of the control loop command. If the **or current value** check box is selected, this field is greyed out (disabled).	Type the desired command mean level (in the units shown).	✗
or current value	This check box enables you to use the current value as the **Set Point** value.	If you want to use this feature, select it. To disable the feature and use the **Set Point** field, deselect it.	—
Amplitude	The **Amplitude** field sets the full scale amplitude of the control loop command, in relation to the **Set Point** value.	Type the full scale command amplitude (in the units shown) that will obtain the 15 psi deviator stress required for preconditioning. You can calculate this value using the following equation: $x = 15 \text{ psi } (\pi r^2)$ where: x is the **Amplitude** value 15 is the level to be achieved for preconditioning (per T 294-92 I) r is the radius of your specimen	✗
Gain control	This control enables the ATS auto gain feature. It ensures that command peaks are achieved.	Make sure that this check box is selected.	D
Pulse time	The **Pulse time** field sets the loading duration for one load cycle.	Type 0.1 (seconds). This time is defined by T 294-92 I.	D

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Cycle time	The **Cycle time** field is used to define the total cycle time (load duration plus recovery time).	Type 1.0 (seconds). This time is defined by T 294-92 I.	D
save for units (button) % pts	These fields define what percent of data is collected during a particular portion of the load cycle.	No editing required. T 294-92 I tests do not require any data collection during the preconditioning portion of the test.	D
Duration	The **Duration** field sets the duration of the test. If a **Schedule** was selected above, the value is determined by that schedule file and this field is disabled (greyed out).	Type 1000 (cycles). This value is defined by T 294-92 I.	D

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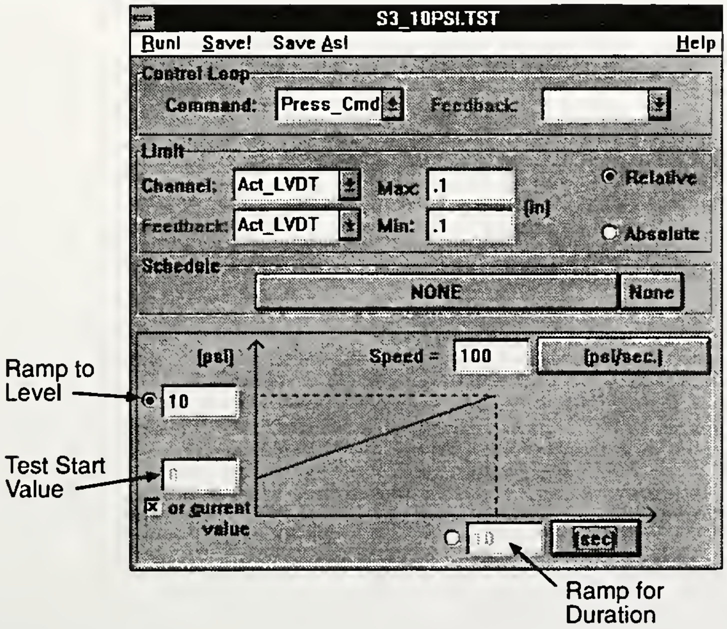
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

S3 (Confining Pressure) Files

When you open an S3 (confining pressure) test file, a window similar to the following appears:



As shown on the following table, you probably will not have to edit any of the parameters on this window for each test. You may want to check the validity of the **Limit** and **Speed** selections.

Parameter	Definition	Action	Key*
Control Loop	The **Command** and **Feedback** pop-up menus select parameters for the control loop. For this type of test, the **Feedback** menu is disabled (greyed out).	Select the desired command variable. For this type of test file, you should select a pressure command.	D
Limit	The **Channel** and **Feedback** pop-up menus and the **Limit** field provide an interlock backup to stop the test in case of specimen failure. When a limit on the selected channel is exceeded, the system transfers control from the **Command** channel to the selected **Limit Feedback** channel.	Select the desired **Channel** and **Feedback** parameters. Type the appropriate limit value in the **Limit** field (in the units shown). The **Limit** should be a value that minimizes the chance of equipment damage. The actual value will depend on channel selection and specimen type.	✓
Schedule	The long button opens a selection window to allow you to select a schedule file for this test. The **None** button selects no schedule for this test.	There is no data collection required when changing confining pressure. Click **None**.	D

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

Parameter	Definition	Action	Key*
Test Start Value	The **Test Start Value** field sets the level at which the pressure ramp will start. If the **or current value** check box is selected, this field is greyed out (disabled).	For this phase of the test, use the **or current value** feature described below.	D
or current value	This check box enables you to use the current value as the **Start at** value.	Make sure that this box is selected.	D
Ramp to Level	The **Ramp to Level** button and corresponding value field sets the level to which the pressure will increase or decrease.	Type the desired pressure (in the units shown).	D
Ramp for Duration	The **Ramp for Duration** button and corresponding value field is an alternative to the **Ramp to** command.	For this test, use the **Ramp to Level** feature described above. Make sure that the **Ramp for Duration** check box is not selected.	D
Speed	The **Speed** field and its corresponding units button sets the rate of the pressure ramp.	Type the desired ramp speed.	✓

* Key: ✗, edit each time you use the template.
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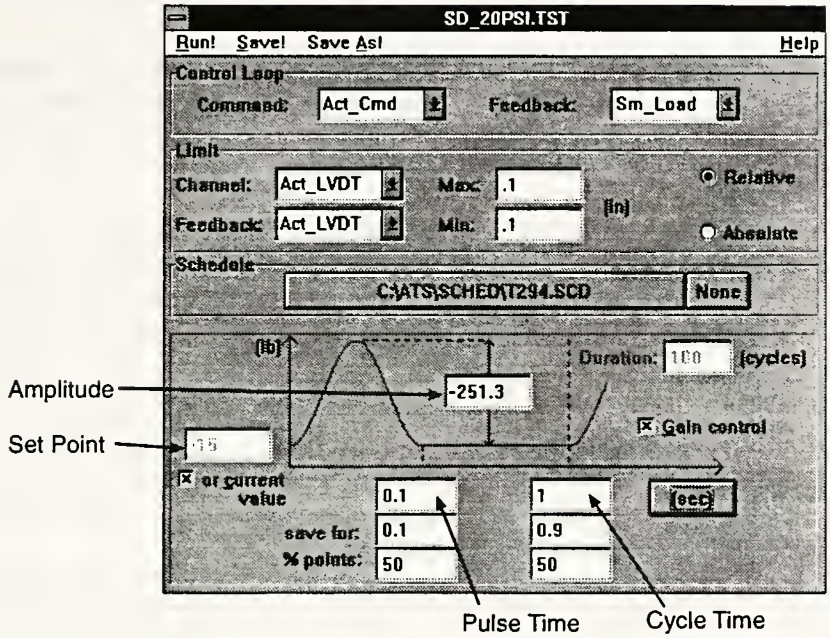
D, set a default value when you use the template the first time.

SD (Deviator Stress) Files

When you open an SD (deviator stress) test file, a window similar to the following appears:



As shown on the following table, you will have to edit the **Set Point** and **Amplitude** parameters on this window for each test. You may also want to check the validity of the **Limit** selections. The rest of the parameters can typically be defined as defaults and saved in the template.

Parameter	Definition	Action	Key*
Control Loop	The **Command** and **Feedback** pop-up menus select parameters for the control loop.	Select the desired command and feedback variables. For this type of test, you should select an axial command and a load feedback.	D
Limit	The **Channel** and **Feedback** pop-up menus and the **Max** and **Min** fields provide an interlock backup to stop the test in case of specimen failure. When a limit on the selected channel is exceeded, the system transfers control from the **Command** channel to the selected **Limit Feedback** channel. The **Relative** and **Absolute** radio buttons select whether the limit values will be actual values relative to the operating range (**Absolute**) or values relative to the starting value of the test(**Relative**).	Select the desired **Channel** and **Feedback** parameters. Type the appropriate limit values in the **Max** and **Min** fields (in the units shown). Select the **Relative** or **Absolute** limit value. The maximum and minimum limits should be a value that minimizes the chance of equipment damage. The actual value will depend on channel selection and specimen type.	✓

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Schedule	The long button opens a selection window to allow you to select a schedule file for this test. The selection defaults to the T294.SCD schedule file. The **None** button selects no schedule for this test. The selected schedule defines the duration of the test and the data collection intervals for the test. If you do not use a schedule file, you need to enter the test duration in the **Duration** field.	If you want to select a different schedule file, click the long button and select the desired schedule file. If you do not want to use a test schedule, click **None** and then use the **Duration** field to define the length of the test.	D
Set Point	The **Set Point** field sets the mean level of the control loop command. If the **or current value** check box is selected, this field is greyed out (disabled).	Type the desired command mean level (in the units shown).	✗
or current value	This check box enables you to use the current value as the **Set Point** value.	If you want to use this feature, select it. To disable the feature and use the **Set Point** field, deselect it.	—
Amplitude	The **Amplitude** field sets the full scale amplitude of the control loop command, in relation to the **Set Point** value.	Type the full scale command amplitude (in the units shown) that will obtain the desired deviator stress. You can calculate this value using the following equation: $x = n(\pi r^2)$ where: x is the **Amplitude** value n is the psi level to be achieved in this test (per T 294-92 I) r is the radius of your specimen	✗
Gain control	This control enables the ATS auto gain feature. It ensures that command peaks are achieved.	Make sure that this check box is selected.	D

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Pulse time	The **Pulse time** field sets the loading duration for one load cycle.	Type 0.1 (seconds). This time is defined by T 294-92 I.	D
Cycle time	The **Cycle time** field is used to define the total cycle time (load duration plus recovery time).	Type 1.0 (seconds). This time is defined by T 294-92 I.	D
save for **units (button)** **% pts**	These fields define what percent of data is collected during a particular portion of the load cycle.	Type the desired data collection distribution. The two **save for** times should add up to the cycle time value and the **% pts** should add up to 100%. For example, if your **Pulse time** = 0.1 and **Cycle time** = 1.0, you could use the following values: **save for** = 0.1 sec, 50% **pts** **save for** = 0.9 sec, 50% **pts** These values would collect 50% of the data points during the loading duration (first 0.1 second) of the load cycle and 50% during the recovery time (last 0.9 second).	D
Duration	If a **Schedule** was selected above, the duration is determined by that schedule file and this field is disabled (greyed out). If no schedule was selected (None), the **Duration** field sets the duration of the test.	If no schedule is selected, type the desired test duration (number of cycles).	D

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D, set a default value when you use the template the first time.

Edit the Sequence File

TYPE1.SEQ and TYPE2.SEQ are the sequence files created to link the previously defined tests for T 294-92 Type 1 and Type 2 tests, respectively. As previously described, these sequences execute the confining pressure ramps and load cycle applications required for the two tests.

Type 1 Sequence

The TYPE1.SEQ file contains the following sequence of tests:

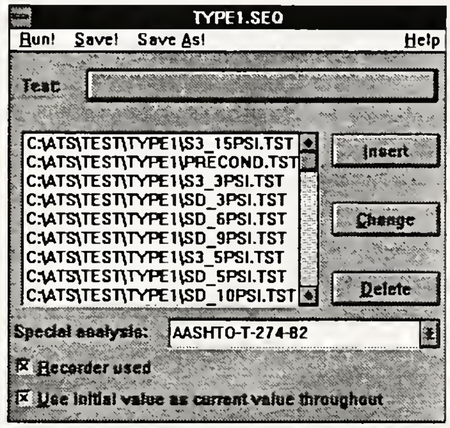
S3_15PSI.TST	Ramp confining pressure to 15 psi
PRECOND.TST	Apply 1000 load cycles at 15 psi SD
S3_3PSI.TST	Ramp confining pressure to 3 psi
SD_3PSI.TST	Apply 100 load cycles at 3 psi SD
SD_6PSI.TST	Apply 100 load cycles at 6 psi SD
SD_9PSI.TST	Apply 100 load cycles at 9 psi SD
S3_5PSI.TST	Ramp confining pressure to 5 psi
SD_5PSI.TST	Apply 100 load cycles at 5 psi SD
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD
SD_15PSI.TST	Apply 100 load cycles at 15 psi SD
S3_10PSI.TST	Ramp confining pressure to 10 psi
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD
SD_20PSI.TST	Apply 100 load cycles at 20 psi SD
SD_30PSI.TST	Apply 100 load cycles at 30 psi SD
S3_15PSI.TST	Ramp confining pressure to 15 psi
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD
SD_15PSI.TST	Apply 100 load cycles at 15 psi SD
SD_30PSI.TST	Apply 100 load cycles at 30 psi SD
S3_20PSI.TST	Ramp confining pressure to 20 psi
SD_15PSI.TST	Apply 100 load cycles at 15 psi SD
SD_20PSI.TST	Apply 100 load cycles at 20 psi SD
SD_40PSI.TST	Apply 100 load cycles at 40 psi SD
S3_0PSI.TST	Ramp confining pressure to 0 psi

Type 2 Sequence

The TYPE2.SEQ file contains the following sequence of tests:

S3_6PSI.TST	Ramp confining pressure to 6 psi
PRECOND.TST	Apply 1000 load cycles at 6 psi SD
SD_2PSI.TST	Apply 100 load cycles at 2 psi SD
SD_4PSI.TST	Apply 100 load cycles at 4 psi SD
SD_6PSI.TST	Apply 100 load cycles at 6 psi SD
SD_8PSI.TST	Apply 100 load cycles at 8 psi SD
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD
S3_3PSI.TST	Ramp confining pressure to 3 psi
SD_2PSI.TST	Apply 100 load cycles at 2 psi SD
SD_4PSI.TST	Apply 100 load cycles at 4 psi SD
SD_6PSI.TST	Apply 100 load cycles at 6 psi SD
SD_8PSI.TST	Apply 100 load cycles at 8 psi SD
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD
S3_0PSI.TST	Ramp confining pressure to 0 psi
SD_2PSI.TST	Apply 100 load cycles at 2 psi SD
SD_4PSI.TST	Apply 100 load cycles at 4 psi SD
SD_6PSI.TST	Apply 100 load cycles at 6 psi SD
SD_8PSI.TST	Apply 100 load cycles at 8 psi SD
SD_10PSI.TST	Apply 100 load cycles at 10 psi SD

You will not need to edit the test sequence file unless the name of one of your test files changes. To edit the sequence file, open the TYPE1.SEQ or TYPE2.SEQ file using the ATS Test menu Edit command. A window similar to the following appears:



Parameter	Definition	Action	Key*
Test	In conjunction with the **Insert**, **Change** and **Delete** buttons, the **Test** button selects the tests to be used in the test sequence file.	Click on the **Test** button and choose the desired test file from the file selection window.	—
sequence table	The sequence table lists the selected tests in the order they will be run to perform the requirements of T 294-92 I testing.	The entries in this table are defined by the **Insert**, **Change**, and **Delete** buttons described next.	D
Insert	In conjunction with the **Test** button, the **Insert** button adds tests to the sequence.	1. Select a test to be inserted using the **Test** button. 2. Select the test in the sequence table that you want the test inserted before. (Or, if you want the selected test to be added at the end of the current list, do not select any test name in the sequence table.) 3. Click the **Insert** button to add the test to the sequence table.	—

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.

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Parameter	Definition	Action	Key*
Change	In conjunction with the **Test** button, the **Change** button replaces a test in the sequence table with a different test.	1. Select a replacement test using the **Test** button. 2. Select the test in the sequence table that is to be replaced. 3. Click the **Change** button to replace the test.	—
Delete	In conjunction with the **Test** button, the **Delete** button removes a test from the sequence table.	Select the test in the sequence table that you want to delete and click **Delete** to remove the selected test.	—
Special analysis	The **Special analysis** pop-up menu selects a data processing method.	For these tests, select the AASHTO-T-274-82 data processing method.	D
Recorder used	This check box enables the data collection processes.	Make sure that this check box is selected.	D
Use initial value as current value throughout	This check box enables the current value when the test is started to be used as the starting value for subsequent tests within the sequence.	To use this feature, the **or current value** option must be selected in the tests within the sequence. For most test applications, this feature would be selected.	D

* Key: ✗, edit each time you use the template.
✓, check and edit if necessary each time you use the template.
D, set a default value when you use the template the first time.